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REFRIGERATION.*

BY

A. R. STEVENSON, JR.

General Electric Company.

HISTORICAL INTRODUCTION.

THE purpose of refrigeration is the promotion of health and comfort. Health is improved by the proper preservation of food; comfort is enhanced by the preparation of frozen delicacies, the cooling of theaters, etc. The widespread use of refrigeration is less than 100 years old and really exists nowhere even to-day except in the United States. Perhaps this is partially responsible for the statement which is sometimes made, that during the last 100 years the average life of man has been increased from 35 to 55 years. Whether this is true or not, it is at least partially confirmed by the figures of the Metropolitan Life Insurance Company,[1] which show that during the last 14 years there was a gain of 4.7 years in the expectation of life for the general population of the United States. Of course, this is not all due to refrigeration, but it would seem unfair not to allow refrigeration to assume part of the credit for this improvement in health.

In both ancient and medieval history, there are references to refrigeration, but these are interesting as isolated instances rather than representative of its general use. The Egyptians

* Presented at the Stated Meeting held Wednesday, February 20, 1929.

[1] "Educating for Longer Life"—pamphlet issued by Metropolitan Life Insurance Company, New York City.

are said to have cooled water in shallow trays of porous material on beds of straw by evaporation. One of the Greek poets wrote a poem criticizing his host for not cooling his wine with snow. Both Alexander the Great and Nero had slaves who brought snow from the mountains. Catherine de Medici took with her to France an Italian cook who knew how to make frozen delicacies. The French Government in the seventeenth century attempted to control refrigeration by granting licenses for the distribution of snow and ice. This raised the prices so high that people would not buy, and the government had to relinquish control. There was no general or widespread use of refrigeration.

In America, where refrigeration has its widest and most general applications, the first record of delivery of ice to the home was in 1802. A most notable instance of the early use of refrigeration for the promotion of health was in 1805 when Frederick Tudor made the first commercial shipment of ice from America to Martinique in the West Indies, to control a scourge of yellow fever.

After the construction of the first large ice house in America in 1805, there grew up rapidly an industry which harvested the ice in our northern states and shipped it to the south in sailing vessels. As early as 1850, the City of New Orleans alone consumed over 50,000 tons annually.

Meanwhile, in England and Europe experiments were being made. In this day of electric refrigeration, it is most interesting to recall that Faraday, the father of our electrical science, might also be called the father of mechanical refrigeration. While working in the Royal Institute in London, in 1824, he discovered that ammonia vapors which had been condensed by compressing and cooling would, when the pressure was removed from the liquid, boil violently and become cold.

In France in 1860, Ferdinand Carré made the first practical ammonia absorption refrigerating machine. During the Civil War a blockade runner brought one of these Carré machines from France to New Orleans. This machine was ordered because of the shortage of natural ice in the southern states, the supply from the North being cut off by the war. At the time, the small amount of ice available in the South sold at about five cents a pound.

It was not until 1877 that the first successful year-round shipments in refrigerator cars were made by Mr. G. F. Swift.

The old proverb, "It is an ill wind that blows nobody good," was illustrated by the great impetus which the serious shortage of natural ice in the year 1890 gave the artificial ice industry. Since then, the industry has grown so rapidly that in 1927 there was three times as much artificial ice manufactured as natural ice harvested.

ICE BOXES.

A generation ago, spring houses, cold cellars, etc., were used extensively for the preservation of food; and they are still used to-day, especially in country communities. In the majority of modern homes, however, the ice box is taken for granted as the proper method of preserving food, and there is no doubt that food can be very well preserved in a well-insulated ice box. Unfortunately, however, the great majority of ice boxes are not well insulated. The following quotation from a paper [2] by Dr. John R. Williams, Secretary of the Milk Commission, Rochester, New York, is of interest:

"The majority of domestic refrigerators are inefficient because they consume too much ice and do not maintain a temperature low enough to prevent food from spoiling. The chief explanation of their inefficiency is to be found in the lack of sufficient and proper insulation.

"The waste from ice meltage because of improper insulation of refrigerators in Rochester homes (population of city, 230,000) amounts to 60,000 tons yearly, or about $350,000.

"Money invested in insulation will be returned many times in the saving in ice bills. Added insulation means not only economy of ice consumption, but also lower temperature in the refrigerator and the less spoiling of food."

Some of Dr. Williams' conclusions are confirmed by calculations shown in Table I.

TABLE I.

Effect of One Inch Additional Insulation upon the Economy of the Ordinary 100-lb. Ice Box.

Saving in ice—1,140 lb. @ 60 cents per 100 lb.		$6.85
42½ board feet additional insulation	$20.00	
6% interest and 10% depreciation		3.20
Net Saving		$3.65

[2] "A Study of Refrigeration in the Home and the Efficiency of Household Refrigerators," read before the Third National Congress of Refrigeration, 1913.

This represents an 18 per cent. saving on the $20.00 investment, as well as a guarantee of better refrigeration.

In the design of any ice box, the question always arises as to what allowances should be made for the doors. The doors are the source of three types of loss:

(*a*) Spilling of cold air when the door is opened.
(*b*) Leakage due to badly fitting doors.
(*c*) Conduction through the door frames which, of necessity, are badly insulated.

The first of these is not so serious as is generally supposed. The weight of air in an average domestic refrigerator is less than one-half pound. Its specific heat is about one-quarter. Spilling out this cold air and completely replacing it by warm dry air is equivalent only to placing ⅛ lb. of water at room temperature into the box.

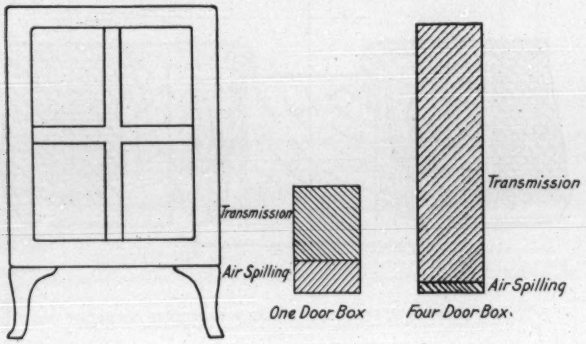
If the warm air is damp, however, moisture will condense out of it when it is chilled; and if the box is artificially refrigerated, this moisture is frozen in the form of frost on the evaporator. At normal room temperatures with reasonably dry air (70° F. and 66 per cent. humidity), this loss due to spilling of air would be about 2 or 3 per cent. of the total refrigeration required by the box if the door is opened 25 times a day. In a 90° room with 100 per cent. humidity, the loss with the same number of openings would be about 6 per cent. In testing boxes, if the door is opened every 15 minutes (100 times a day) to read thermometers, the error is not very serious in dry rooms; but if the test room is highly humidified, the refrigeration required may be increased as much as 25 or 30 per cent.

Leakage due to badly fitting doors can, to a large extent, be overcome by the use of cushion gaskets.

The conduction of heat through the door frames is much more serious. Calculations and tests seem to indicate that, even in a very well-constructed four-door box, the heat conduction through the door frames is about 5 per cent.; while with less efficient door frames, the loss may be as high as 25 or 30 per cent. of the total box leakage. Under ordinary conditions of operation, therefore, the conduction through the door frames is very much more important than the loss

due to spilling of air. This fact has a decided bearing on the decision as to the number of doors used on a refrigerator box. Fig. 1 illustrates the relative magnitudes of these losses.

FIG. 1.

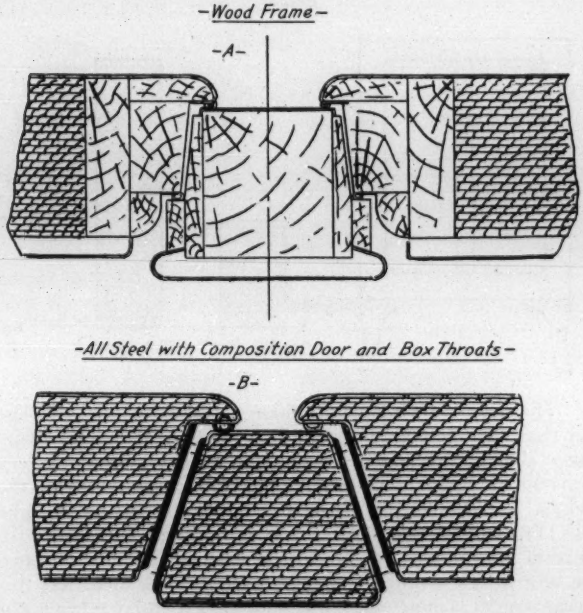


The opening of one small door out of four may spill less air than the opening of one big door, but the four small doors have double the perimeter of door frames, and it is very difficult to insulate properly the cross pieces between the doors. Of course, one door would be unwieldy on a large box; but when an extra price is asked for a small ice box with several small doors, so small that platters have to be tipped on edge to go through the openings, with the idea that this arrangement is more efficient than a less expensive refrigerator with one door large enough to form a convenient opening, it would appear that a mistake is being made.

The design of the door edges, of course, has a large effect on these figures. Fig. 2 shows the type of door edges on a conventional box and also a new type of door edge construction which will conduct less than one-third the heat. The losses through the center section of a conventional type of two-door box would be about 9.7 per cent., while the losses through the same part of a box of the new design would be only about 2.7 per cent. of the total heat leakage to the box.

The other parts of the framework of the conventional design of box cause conduction losses similar to those we have just discussed for the door edges. Fig. 3 shows that,

FIG. 2.



Ratio of Losses $\frac{A}{B}$ = 360%

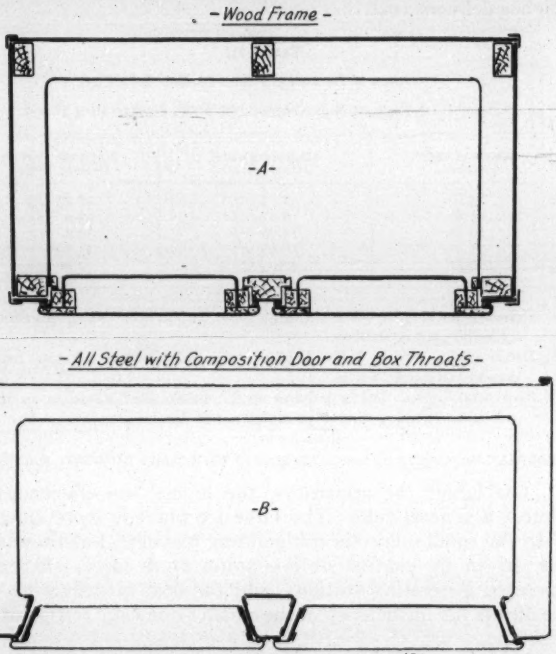
Ratio of Losses to Total Losses

A = 9.7%

B = 2.7%

in the conventional case, these "parasitic" losses are about 20 per cent. of the total losses of the box; whereas with the new construction, the "parasitic" losses have been reduced to about 5 or 6 per cent. of the total losses of the box.

FIG. 3.



	(A)	(B)
Actual Losses B.T.U/HR	184	166
Calculated Losses (Assuming Complete Insulation)	147	157
Losses Due to Doors, Frame Etc.	37	9

COST OF DELIVERY OF ICE.

Whether ice is harvested from a natural source or made in an artificial ice plant, the actual cost of ice is very small compared with the cost of retailing it. The price of ice in cities is approximately 60 cents per hundredweight, and at least half this price is the delivery cost. In widely scattered

communities the price is still higher, largely because of the higher delivery cost.

TABLE II.

Tabulation of Ice Delivery Costs in New York City.

Copied from Page 12 of the September, 1921, *Refrigerating World.*

Weight of Unit Delivered.	Minimum Cost of Delivery Cents.	Maximum Cost of Delivery Cents.
15 lb.	7.74 (*a*)	17.25 (*b*)
25 lb.	9.23 (*a*)	23.5 (*c*)
50 lb.	12.96 (*a*)	34.3 (*c*)
75 lb.	16.95 (*a*)	41.50 (*c*)
100 lb.	20.05 (*a*)	47.20 (*c*)

(*a*) Driver does not enter house but drops ice at curb in accordance with standing order on card in window.

(*b*) Driver enters, goes up half a flight of stairs and examines box, goes back to wagon and carries ice up.

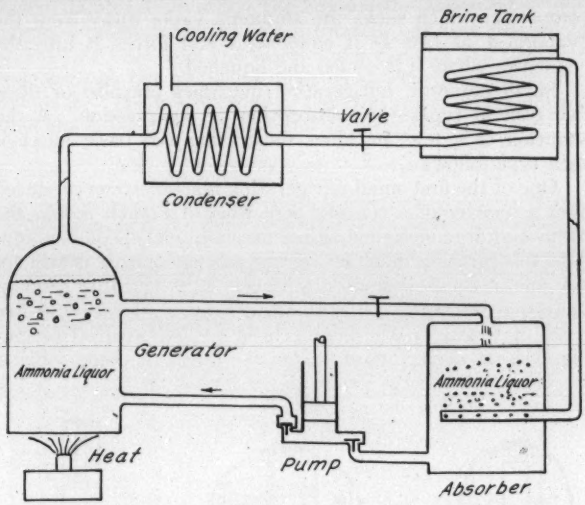
(*c*) Apartment house. Driver inquires up the dumbwaiter, sends ice up dumbwaiter and goes up himself to lift ice out of dumbwaiter into ice box.

GENERAL COMPARISON OF LARGE ICE PLANTS WITH SMALL DOMESTIC MACHINES.

The larger the apparatus, the higher the efficiency—is almost a general rule. The large ice plant is more efficient than the small domestic refrigerating machine, but they both are driven by central station power from large, efficiently operated generating stations, and the cost of delivering the ice offsets the inefficiency of the smaller domestic refrigerating machine.

The large ice plants are of two types—absorption and compression. The absorption system is illustrated in Fig. 4. Heat applied to the generator boils ammonia out of the water. The ammonia vapor under pressure goes to the condenser where it is liquefied, and then through an expansion valve where the pressure is reduced. In the evaporator within the brine tank, the liquid ammonia boils into a vapor absorbing heat and thus doing refrigeration. The vaporized ammonia is sucked into the cold water in the absorber. The water which has absorbed ammonia is called "rich liquor," and is pumped back into the generator; while the water in the generator out of which the ammonia has been boiled is called

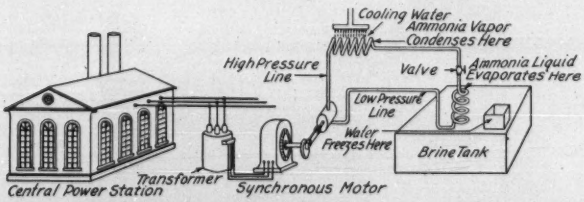
FIG. 4.



"weak liquor," and is allowed to circulate back into the absorber. This is, in general, the principle of the Carré machine which was imported during the Civil War into New Orleans.

The compression system is illustrated in Fig. 5. In this

FIG. 5.



case, the generator which forces the ammonia into a condenser under pressure, and the absorber which sucks the ammonia

vapor away from the evaporator, are both replaced by a compressor which sucks the ammonia vapor away from the evaporator as fast as it evaporates and forces it into the condenser where it is cooled and liquefied.

Small domestic refrigerating machines are also of these two general types—i.e., absorption or compression. A description of a few machines illustrating the basic ideas of each type follows:

One of the first small refrigerating machines was produced over a quarter of a century ago, when a French monk, the Abbé Audiffren, designed an hermetically sealed compression-type refrigerating machine. Strangely enough, it is still today one of the best small machines. It is said that some of these machines are still running in France after twenty-five years of service, never having been refilled with oil or gas. Fig. 6 shows a diagram of the interior of the machine. Fig. 7

FIG. 6.

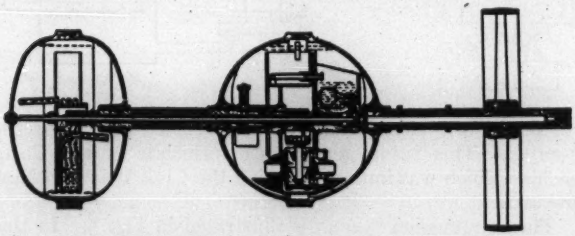
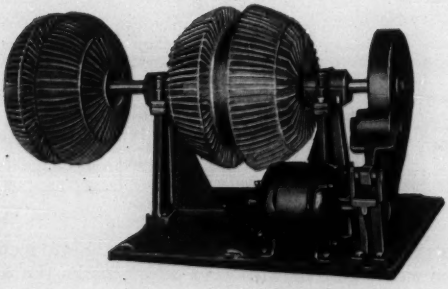
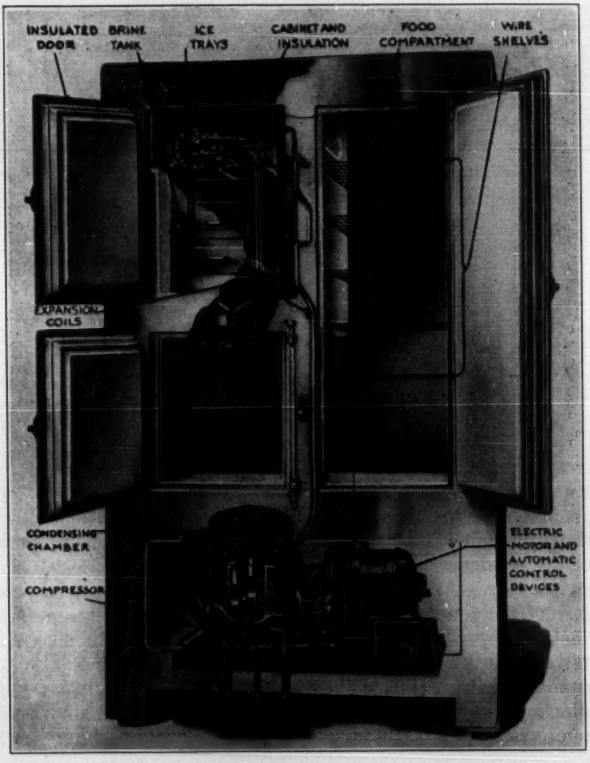


FIG. 7.



shows the exterior of an air-cooled model. It is a completely sealed dumbbell in which the compressor hangs on a pendulum. When the dumbbell is rotated, one end grows cold abstracting heat from the surrounding medium and the other end becomes hot giving up heat to the medium which surrounds it. There is no stuffing box; the power is transmitted from the outside to the inside by gravitation.

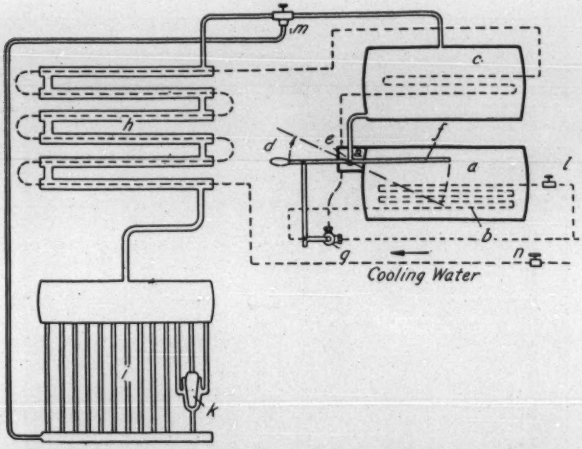
FIG. 8.



Ten or fifteen years ago, designers in America began to experiment with small machines. Most of these were compression machines similar to those used in large ice plants, but, of course, very much smaller. Fig. 8 shows a typical example.

In Europe, particularly in Germany, the development of the small machines followed the absorption principle. Fig. 9

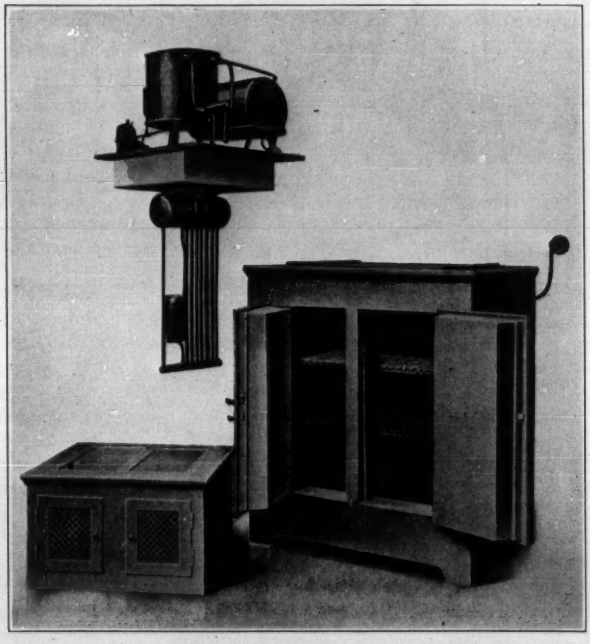
FIG. 9.



is a diagrammatic sketch of a machine developed by Dr. Rumpler. This is what is called an intermittent absorption machine. When heat is applied to the boiler or generator, the ammonia vapor is evaporated and forced under pressure to the condenser where it is liquefied and then passes to the evaporator. After about an hour's boiling, when the temperature of the generator has reached a predetermined value, the heat is automatically shut off and the generator is then cooled with cold water. As the generator cools, it begins to absorb ammonia vapor, thus reducing the vapor pressure to a point which causes the liquid ammonia in the evaporator to evaporate. After several hours, when most of the liquid ammonia

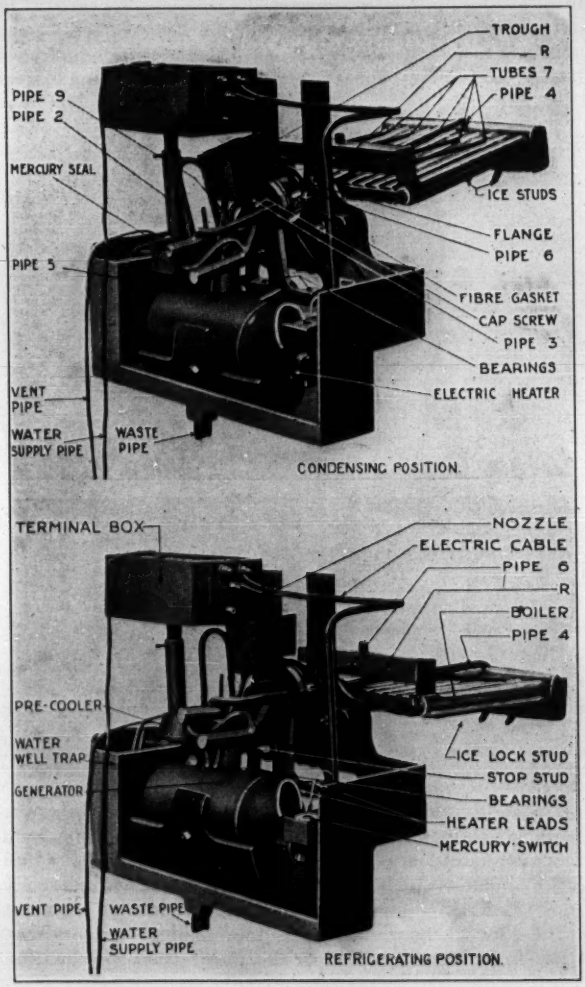
in the evaporator has evaporated, the process is repeated. In an intermittent machine of this kind, the pipe connecting the generator and the condenser should be above the liquid level during the boiling operation, and below the liquid level

FIG. 10.



during the absorbing operation. As can be seen from the diagram, this is taken care of in Dr. Rumpler's machine by a pivoted connection. The pipe is raised above the liquid level by hand when the machine is started. It automatically drops below the liquid level when the thermostat trips out at the time the cycle changes from boiling to absorbing. It has to be reset by hand in the upper position when the

FIG. 11.


TROUGH
R
TUBES 7
PIPE 4
PIPE 9
PIPE 2
MERCURY SEAL
ICE STUDS
FLANGE
PIPE 6
PIPE 5
FIBRE GASKET
CAP SCREW
PIPE 3
BEARINGS
ELECTRIC HEATER
VENT PIPE
WATER SUPPLY PIPE
WASTE PIPE
CONDENSING POSITION.
TERMINAL BOX
NOZZLE
ELECTRIC CABLE
PIPE 6
R
BOILER
PIPE 4
PRE-COOLER
WATER WELL TRAP
GENERATOR
ICE LOCK STUD
STOP STUD
BEARINGS
HEATER LEADS
MERCURY SWITCH
VENT PIPE
WASTE PIPE
WATER SUPPLY PIPE
REFRIGERATING POSITION.

next cycle is started. This figure also illustrates another feature which is necessary in an intermittent absorption machine of this kind. There is always some water boiled over with the ammonia, and after a certain number of cycles sufficient water will have collected in the bottom of the evaporator to prevent the ammonia from evaporating. It is then necessary during the absorption period to turn the valve (*M*) to a position so that this water from the bottom of the evaporator can be sucked back into the absorber, after which the valve (*M*) is turned back to its original position.

A further development of a machine operating on the Rumpler principle is shown in Fig. 10.

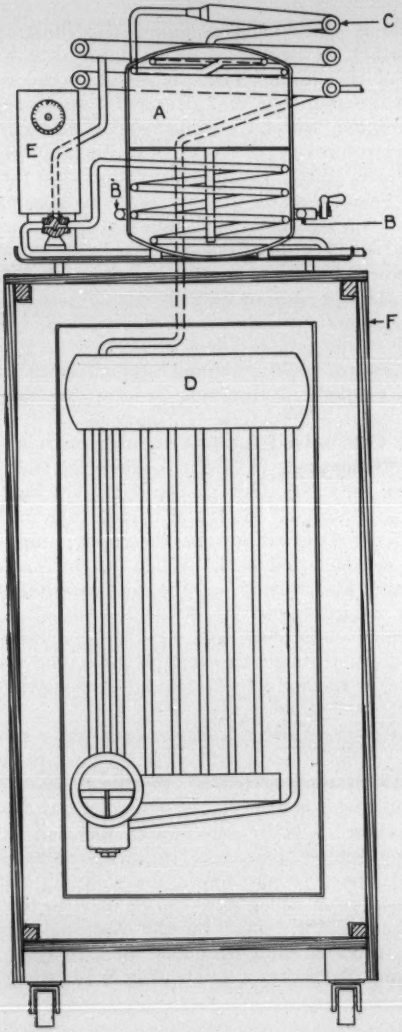
Fig. 11 shows a diagram of the Keith Electric Refrigerator which solves the first problem in another way. The whole refrigerator tips upon a pivoted support as the ammonia is boiled or evaporated from one side of the system to the other.

Stuart Otto solved the first problem without the use of internal moving parts (Fig. 12). When the gas burners (*B*) are lighted, the vapor pressure created in the lower compartment forces almost all the liquid up the tube into the upper compartment (*A*) where it boils, the vapor going out through a tube above the liquid level. When the gas is turned off and the cooling water turned on, the condensation of vapor in the lower compartment sucks all the liquid down again. The returning vapor then comes back through compartment (*A*) and down through the vertical tube, the lower end of which is below the liquid level as desired during the absorption period.

Fig. 13 shows a diagram of an evaporator developed by Mr. Otto. This illustrates how the second problem can be solved without moving parts. In this diagram, it will be noticed that there is a special compartment at the bottom of the evaporator to collect the water which is boiled over. When the machine changes to the evaporating part of the cycle, the vapor pressure forces the water up into another compartment from which it is sucked back to the generator.

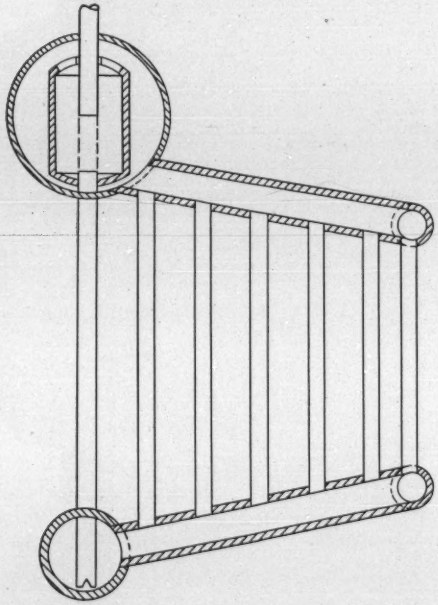
The Ice-O-Lator, made by the National Refrigeration Company, the Copeland Products, Inc., in their Silica Gel machine, and the Safety Car Heating & Lighting Company,

FIG. 12.



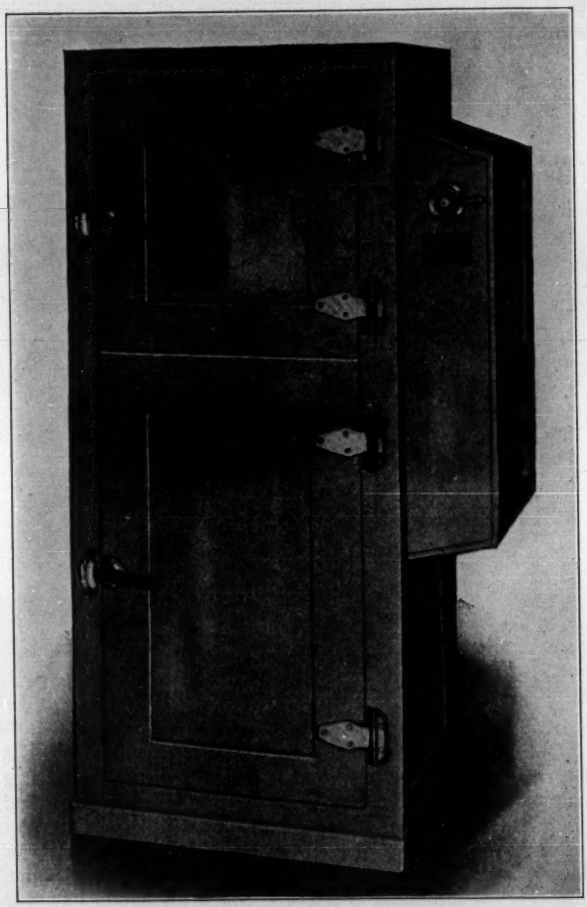
also with a Silica Gel machine, all solve both these problems in a still different way by eliminating the water entirely, using a porous material as a solid absorbent.

FIG. 13.



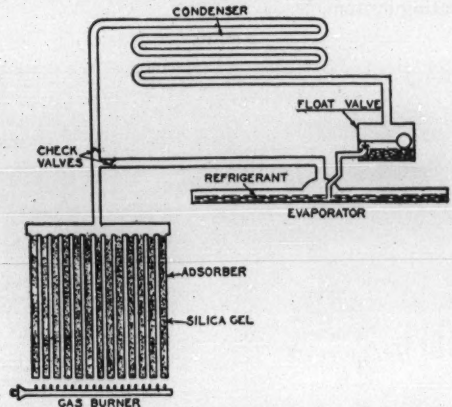
One of the most interesting absorption machines is the Electrolux which was invented in Sweden and is now being manufactured by the Servel Corporation. (See Figs. 15 and 16.) This is not an intermittent but a continuous type of absorption machine. The pressures on the high and low sides of the system are equalized by the insertion of hydrogen, although the ammonia pressure is much higher on one side of the system than on the other according to Dalton's laws

FIG. 15.



of partial pressure. The circulation around this system is obtained by a percolator action.

FIG. 14.



Diagrammatic Sketch Showing the Arrangement of the Silica Gel System

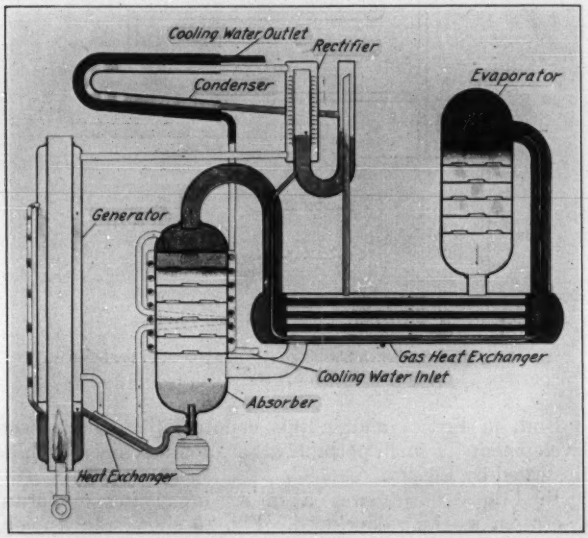
Both in France and in this country, there have been developments of small portable absorption machines, such as illustrated by Fig. 17.

In France, there was a rather interesting miniature absorption machine developed. Fig. 18 shows the Rapide. A bottle of concentrated sulphuric acid is connected to a carafe of water. By means of a hand-operated air pump, the air is removed from the system, whereupon, because of the great affinity of sulphuric acid for water vapor, the water vapor pressure is reduced to such a point that it evaporates rapidly in the carafe and the latent heat of evaporation freezes the remaining water solid in approximately one minute.

Along the lines of compression machines, another rather novel French development was the Corblin compressor, shown in Fig. 19. This avoids the use of a stuffing box by trans-

mitting the power through a flexed diaphragm. Hydraulic pressure is built up and relieved on one side of the diaphragm, while the other side of the diaphragm sucks in and forces out the refrigerant, causing it to circulate through the refrigerating system.

FIG. 16.

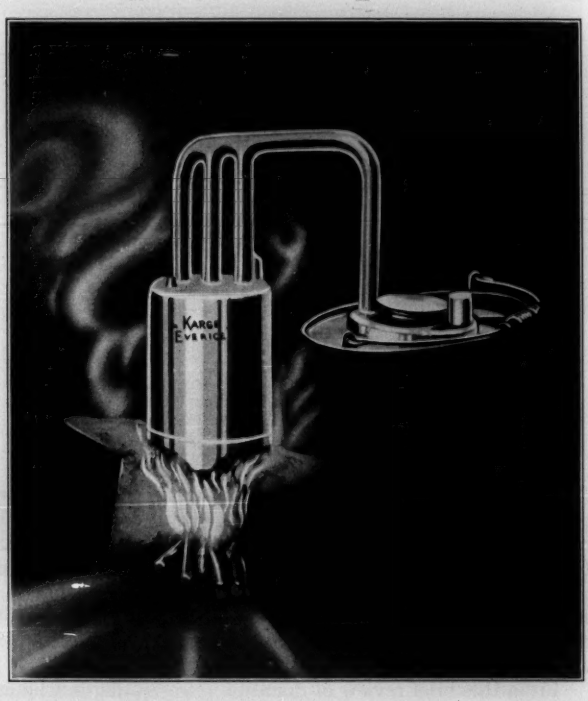


In Switzerland, the Escher Wyss Company brought out a machine called the Autofrigor [3] shown in Fig. 20. In May, 1927, there had already been made about 7,000 of these machines. The stuffing box is avoided in a very novel way. The rotor of the motor is inside the machine, while the stator is outside. There is a thin, high-resistance, non-magnetic metal shell in the air gap of the motor, separating the rotor from the stator.

[3] "Performance Tests on the Small Refrigerating Unit Called the Autofrigor," *Zeitschrift für die gesamte Kälte-Industrie*, May, 1927.

In America, the Savage Arms Company has developed a very novel type of machine with still another scheme for eliminating the stuffing box. The fundamental principle is illustrated by Fig. 21, which is taken from a recent paper by

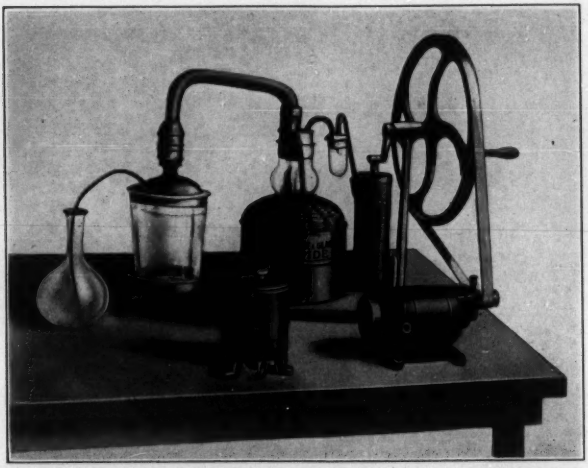
FIG. 17.



Mr. J. G. DeRemer before the American Society of Mechanical Engineers. In this old Archimedes spiral, the force of gravity holds the liquid in the lower half of the screw threads while the rotation of the threads gradually moves the liquid upward through the pipe. The Savage Arms machine operates on a

similar principle, but the force of gravity is replaced by a much higher centrifugal force. Fig. 22 shows one of their machines as actually manufactured.

FIG. 18.



The idea of refrigeration with compressed air has always been attractive. One of the most successful compressed air refrigerating machines was the Odin, developed by Mr. Ivar Lundgaard, which is illustrated in Fig. 23. This machine can best be described by saying that it is similar to a hot air engine run backward. There were about one hundred of these machines made, and I have heard of very little trouble with them.

From this brief review of domestic refrigerating machines of the absorption and compression type, it will be seen that, although in an absorption machine the motor-driven compressor has been replaced by a heating and cooling device, this simplification is probably more than offset by the other problems peculiar to absorption machines. Although the

FIG. 19.

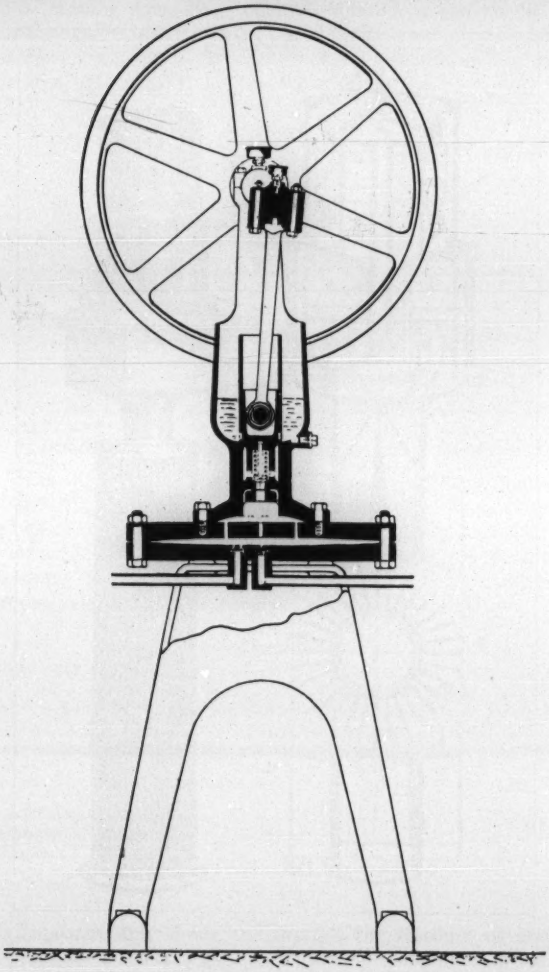
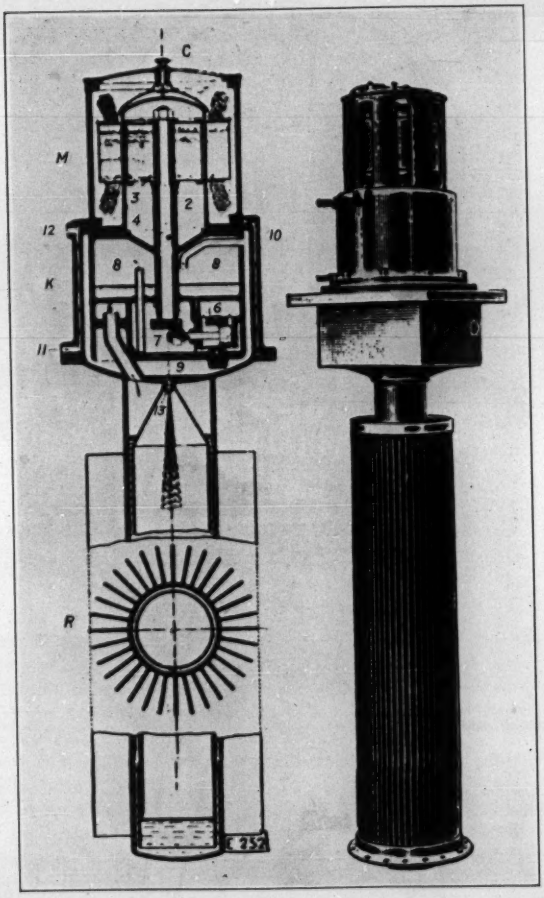
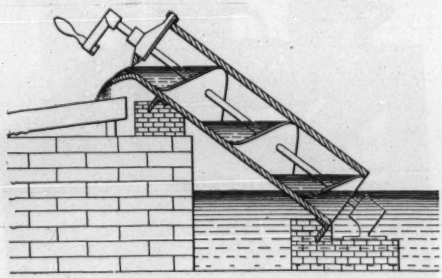


FIG. 20.



major moving parts have been eliminated, it can hardly be said that there are no moving parts, because even the simplest absorption machines on the market have thermostatically operated valves either for the water or the gas.

FIG. 21.



SUMMARY OF VARIOUS TYPES OF REFRIGERATING MACHINES.

It is only during comparatively recent years that domestic refrigerating machines have begun to be seriously considered, and there are now about 104 companies either manufacturing or about to manufacture domestic refrigerating machines. There are a great many different types under consideration, a rough classification of which is given in Table III.

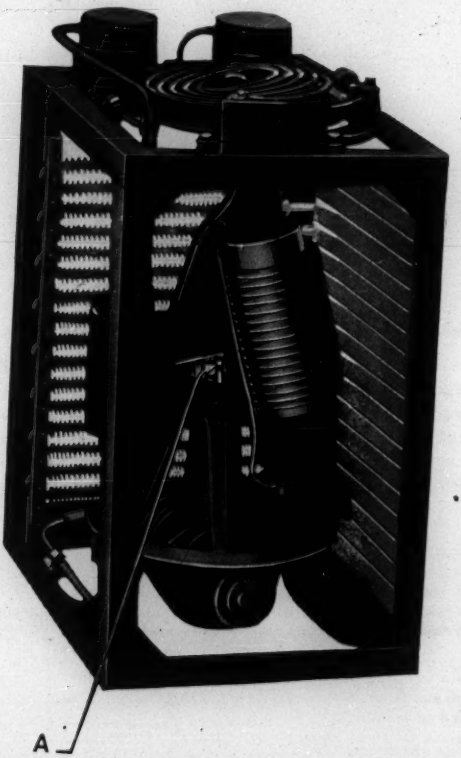
TABLE III.

Vapor Compression Machines:		
(*a*) Conventional type using a stuffing box and electric motor	46	
(*b*) Using a stuffing box and a water motor	1	
(*c*) Stuffing box eliminated by enclosing the motor in the machine	17	
(*d*) Stuffing box eliminated, but motor outside	7	
		71
Absorption machines		22
Compressed air machines		4
Unknown		7
Total		104

Approximately 6 kw-hr. through the medium of one of these small electrically driven compression machines operating

at the ordinary evaporator temperatures (approximately 20° F.) has a refrigerating effect equivalent to the melting of approximately 100 lb. of ice. A comparison of the cost of

FIG. 22.



producing household refrigeration by various methods is shown in Table IV.

FIG. 23.

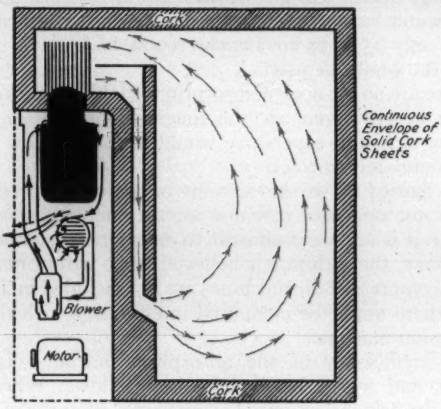


TABLE IV.

	Average Operating Cost of Producing Refrigeration Equivalent to the Melting of 100 lb. of Ice
Ice, at 60 cents per hundredweight	$0.60
(1) Electrically operated, air-cooled compression machine—6 kw-hr. at 3 cents per kw-hr.	0.18 [4]
Water-operated compression machine—720 cu. ft. at 4 cents per 100 cu. ft.	0.29
(2) Electrically heated, water-cooled absorption machine—12 kw-hr. at 3 cents per kw-hr., neglecting cost of water	0.36
Electrically heated, air-cooled absorption machine—24 kw-hr. at 3 cents per kw-hr.	0.72
Gas-heated, water-cooled absorption machine—133 cu. ft. at $1.35 per 1,000 cu. ft., neglecting cost of water	0.18
Gas-heated, air-cooled absorption machine—266 cu. ft. at $1.35 per 1,000 cu. ft.	0.36

[4] If these machines were water cooled, their power consumption would be approximately 20 per cent. less. The fact that most manufacturers of small compression machines have abandoned water cooling, even at a considerable sacrifice in efficiency, is very significant.

In Table IV the figures are based on the actual cost of electricity, water, and gas in the City of Schenectady. The cost of water for the absorption machines has been neglected because only 25 to 75 cu. ft., per 100 lb. of ice, at 4 cents per 100 cu. ft., would be used.

There are no air-cooled absorption machines on the market and the figures given are the roughest kind of engineering estimate, although experience would probably show them to be approximately correct.

The figures as to the amount of water required by the water-motor operated machine are an engineering estimate, but since it is not very difficult to calculate how much water is necessary, the estimate is believed to be within reason.

The compressed-air machines are not included in Table IV. One of them might be compared in efficiency with the vapor compression machines.

The inefficiency of the absorption machines is largely inherent and might be explained as follows: Whereas the electrically driven compression machine, in spite of the low electrical efficiency of small motors and the poor mechanical efficiency of small compressors, actually utilizes about 20 per cent. of the electric energy in pumping the gas, the absorption machine utilizes only about 10 per cent. of the energy put into the electric heating unit in pumping the gas. It must be remembered that the absorption machine, although chemical by nature, actually has to perform the mechanical work of pumping the refrigerant from a low pressure to a high pressure. The vapor is sucked into a cold medium (usually cold water), and then the medium is heated, causing the vapor to be expelled under pressure. The high-grade electric energy,[5] however, is not used directly to cause this pumping action, but is first degraded into heat and then the heat is used to produce mechanical work. The efficiency of any device for changing heat into mechanical work is inherently very low. A perfect heat engine has a very low theoretical performance given by the Carnot formula:

[5] 11 cu. ft. of gas burned in an absorption refrigerating machine will produce about the same refrigerating effect as 1 kw-hr. used to heat the same machine electrically. The economic hope of these machines is in using this less expensive form of heat.

$$\text{Carnot efficiency} = \frac{T_1 - T_2}{T_1},$$

where T_1 = the high temperature in degrees above absolute zero,

T_2 = the low temperature in degrees above absolute zero.

The efficiency is therefore seen to depend on the temperature range, which with these absorption machines is from 212° F. to a temperature that might be as low as 85° F. if water cooling is employed. Therefore,

$$T_1 = 460 + 212 = 672° \text{ absolute},$$
$$T_2 = 460 + 85 = 545° \text{ absolute},$$
$$\text{Carnot efficiency} = \frac{672 - 545}{672} = 18.9 \text{ per cent.}$$

It is thus seen that an absolutely perfect water-cooled absorption machine would have about the same efficiency as the present imperfect compression machines. But, just as it is difficult to make a small compression machine where the useful work is more than about 20 per cent. of the input, so up to the present it has been impossible to make an absorption machine which approaches its theoretical efficiency. The actual efficiency of compression of the water-cooled absorption machines is about half the theoretical figure, or approximately 10 per cent.[6] Of course, the coefficient of performance is higher.

[6] This is only the efficiency of the heat engine half of the machine. The coefficient of performance of the refrigerator operating between 85° condenser temperature and 20° evaporator temperature, would be

$$T_c = 460 + 85 = 545° \text{ abs.},$$
$$T_e = 460 + 20 = 480° \text{ abs.},$$
$$\text{Coeff. of performance} = \frac{T_e}{T_c - T_e} = \frac{480}{65} = 7.4.$$

This could not be obtained. Practically, in a small refrigerating machine it would not be higher than 2.00.

The overall coefficient of performance of the whole machine would be the product of the efficiency of the heat engine by the efficiency of the refrigeration cycle, or

$$10\% \times 2.00 = 20\%.$$

There are no air-cooled absorption machines available,[7] but the theoretical efficiency of such a machine can be estimated. It would probably be uneconomical without the use of a fan to furnish enough cooling area to bring the internal temperature of the absorber to within 30 degrees above the surrounding air. Therefore, in an 80° room, the air-cooled absorption machine would operate between 212

Compare this with the figures in Table IV. The heat content of 133 cu. ft. of gas @ 550 B.t.u. per cu. ft. would be 73,000. Melting 100 lb. of ice would absorb 14,400 B.t.u.

$$\text{Coeff. of performance} = \frac{14,400}{73,000} = 19.8\%.$$

[7] Since this was written, figures on an air-cooled adsorption refrigerating machine have been given by George E. Hulse in "Freight Car Refrigeration by an Adsorption System Employing Silica Gel," *Refrigeration Engineering*, Vol. 17, No. 2, February, 1929. On page 52, Mr. Hulse states that a maximum activating temperature of 450° F. is required for a Silica Gel adsorption unit. He further states that the thermal efficiency is about 30 per cent.

The efficiency of a theoretically perfect heat engine operating between these temperatures could be calculated:

$$T_1 = 460 + 450 = 910,$$
$$T_2 = 460 + 110 = 570,$$
$$\text{Carnot efficiency} = \frac{910 - 570}{910} = 37\%.$$

But even with this higher Carnot efficiency for the heat engine, the overall coefficient of performance of the whole machine is within 5 per cent. of the figure given in Table IV. In the discussion, Mr. Hulse states that 135 lb. of Propane are consumed in producing one ton of refrigeration. The heat of combustion of Propane is 22,700 B.t.u. per lb. One ton of refrigeration is 288,000 B.t.u.

$$\text{Actual coefficient of performance} = \frac{288,000}{135 \times 22,700} = 9.4\%.$$

In Table IV, 266 cu. ft. of gas @ 550 B.t.u. per cu. ft. is required to produce 100 lb. of refrigeration.

$$\text{Actual coefficient of performance} = \frac{14,400}{266 \times 550} = 9.85\%.$$

That these figures, therefore, agree within 5 per cent. is remarkable because those in Table IV were estimated for a small domestic machine, whereas Mr. Hulse's figures are on a much larger machine for refrigerator car cooling. Corresponding to Mr. Hulse's figures, a small Silica Gel air-cooled absorption machine for domestic use would have an even lower efficiency than that estimated in Table IV.

and 110° F. Thus:

$$T_1 = 460 + 212 = 672,$$
$$T_2 = 460 + 110 = 570.$$

$$\text{Carnot efficiency} = \frac{672 - 570}{672} = 15 \text{ per cent.}^{7}$$

Therefore, the air-cooled absorption machine would have only three-quarters the theoretical efficiency of the water-cooled machine. The ratio of actual to theoretical efficiency would be much smaller for the air-cooled machine than for the water-cooled, because the air-cooled machine could not be so well insulated during the heating period and the weight of material, such as cooling fins, etc., which would have to be heated and cooled in an intermittent machine, would be greater. In addition to the lower efficiency of the generator and absorber, the refrigerating coefficient of performance depending on the condenser and evaporator temperatures is also lower in the air-cooled machine. Thus where the actual efficiency of the heat engine in a water-cooled absorption machine is about 10 per cent., the actual efficiency in the air-cooled absorption machine would be about 5 per cent.

It would appear that, until some further improvement in the efficiency of absorption machines is made, the cost of operating them electrically will be materially greater than that of compression machines. But figures seem to indicate that 11 cu. ft. of gas burned in an absorption refrigerating machine will produce about the same refrigerating effect as 1 kw-hr. used to heat the same machine electrically. Eleven cubic feet of gas cost about half as much as 1 kw-hr.; therefore, the water-cooled absorption machine, when heated by gas, is competitive with the compression machines. But water cooling is an added complication, and the foregoing figures seem to indicate that, without further improvements, an air-cooled absorption machine, even when gas heated, would be expensive to operate.

REQUIREMENTS FOR DESIGN OF DOMESTIC REFRIGERATORS.

Ice-Box Temperature Requirements

The U. S. Department of Agriculture [8] shows the following ratios of bacteria growth in milk at various temperatures.

[8] U. S. Department of Agriculture Bulletin No. 642.

FIG. 24.

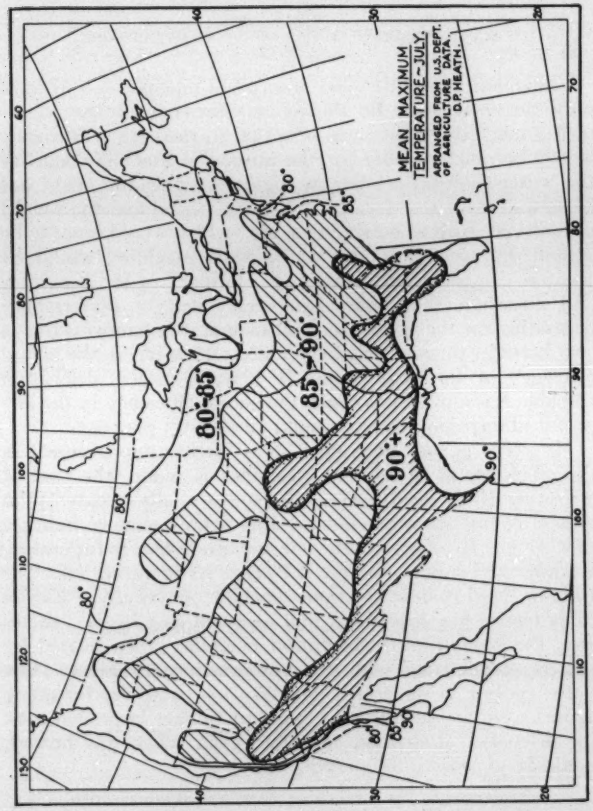

MEAN MAXIMUM TEMPERATURE—JULY.
ARRANGED FROM U.S. DEPT. OF AGRICULTURE DATA. D.P. HEATH.
80-85
85-90
90+

TABLE V

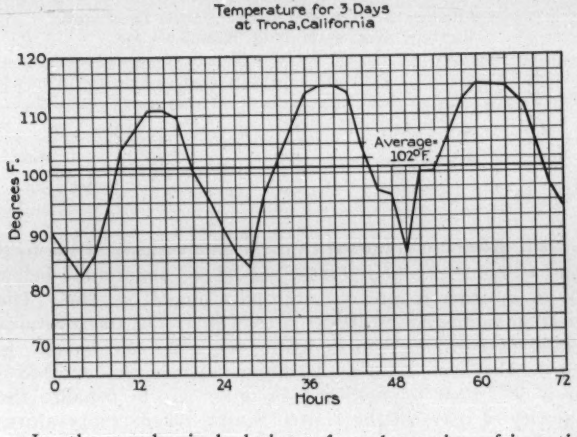
Ratios of Bacteria Growth in Milk Stored at Various Temperatures.
Ex.: U. S. Dept. of Agriculture Bulletin No. 642.

Temp. ° F.	Fresh.	Hours of Storage.			
		24	48	72	96
40	1	1.25	1.21	2.66	5.10
50	1	3.34	31.1	1,464.0	9,629.0
60	1	398.0	8,772.0	79,809.0	288,232.0

It is generally admitted that the temperature of the food compartment in a refrigerator should be maintained below 50° F. in order to prevent multiplication of bacteria. The question immediately arises as to what room temperatures should be considered in designing machines and boxes. It was decided some time ago to design the machines and boxes for a 90° room temperature, in order not to penalize the majority of users in the United States, where temperatures only for very short periods exceed 90° F. It takes time for heat to leak through the walls of a well-insulated refrigerator box. Therefore, when the temperature rises for a few hours at midday, the effect on the refrigerator is not so serious as might be supposed.

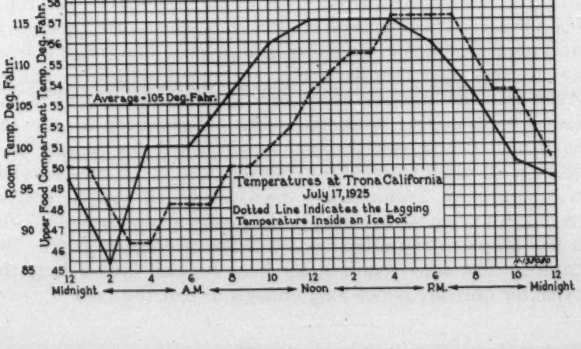
Having designed the machines for a 90° room temperature, the further question arose as to how the machines would perform in still higher temperatures. The hottest temperature records to be found in the United States were at Trona, California. The temperature cycle for the worst three days at Trona, California, is shown in Fig. 25. The range is from 82° to 115°, and the average is 102°. An artificially heated room was run through this cycle of temperature and it was found that in the refrigerator the temperature on the top shelf of the food compartment on the third day ranged from 46.5° F. at night to 57.5° in the afternoon. Fig. 26 shows the temperature at Trona on the third day which was the hottest day of July, 1925. It ranges from 86° at night to 115° for a few hours in the afternoon, and the average is 105°. Because of the time required for heat to leak into a box, the cycle for one day is not long enough to test the box.

FIG. 25.



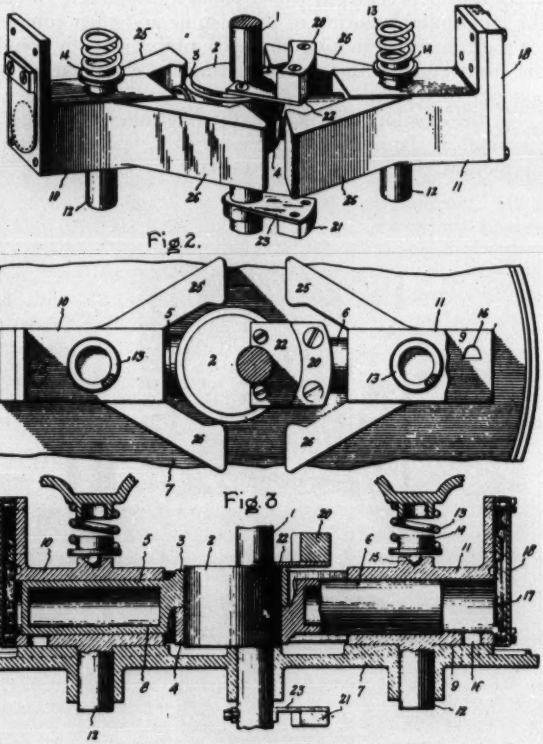
In the mechanical design of a domestic refrigerating machine, there are various interesting problems which arise. It is most important that the machines be quiet and vibrationless. A big step in the reduction of noise was made when the compressor was designed to operate at motor speed,

FIG. 26.



thus eliminating gearing, belting, etc., because it is quite difficult to completely eliminate the noise from any of these systems of speed reduction. In addition to muffling the

FIG. 27.

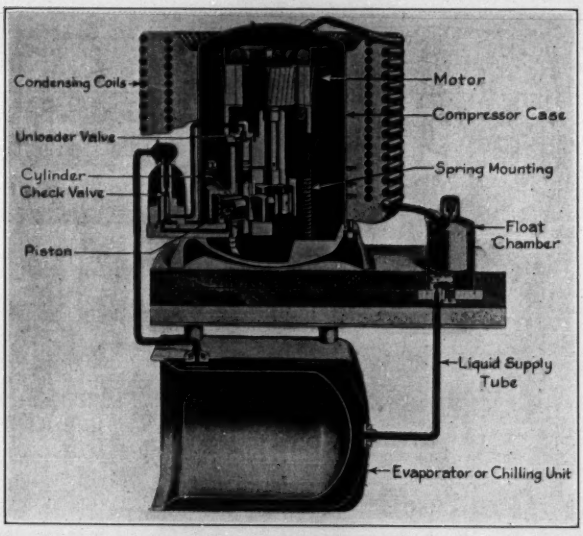


exhaust from the cylinders, it is advisable to balance the machine. Fig. 27 illustrates how the oscillating cylinder construction lends itself to balancing. Reciprocating machines are ordinarily balanced by making the counterweight

just half as big as it should be in order to balance the longitudinal motion of the piston. This is because there is nothing to balance the counterweight during its transverse motion. With the oscillating cylinder construction, it is possible to make the counterweight heavy enough completely to balance the longitudinal motion of the pistons and then compensate for the transverse motion of the counterweight, by weighting the front ends of the cylinders which are oscillating in the opposite direction.

In the development of a really quiet electric refrigerating machine, it is not only necessary to spring mount the mechanism, but it is also necessary to enclose the whole

FIG. 28.



mechanism in an hermetically sealed casing. If the machine is only spring mounted, noise is transmitted by the air around the machine. If the machine is only enclosed in an her-

metically sealed casing without a spring mounting, the noise is transmitted by metallic conduction to the casing, and thus to the air. Fig. 28 illustrates the interior of a machine which is mounted in this way. It was at first thought that contact between the motor stator and the casing was necessary in order to get the heat out of the motor; but when the spring mounting was tried, it was found that sulphur dioxide was a sufficiently good convecting medium to furnish all the heat transfer necessary.

The question of heat dissipation by natural convection and radiation from finned surfaces is also a very interesting one on which a whole separate paper could be written. The question is asked again and again as to whether the white paint on such a machine reduces the heat transfer. It is quite the contrary, as has been shown in various papers. Tests made by Fessenden and Marin at the University of Michigan [9] on steam radiators, show this; and even as early as 1911, there is an article describing tests by Professor J. R. Allen, of the University of Michigan, in which he shows that radiators painted with pigment paints are 25 per cent. better than those painted with copper, bronze, or aluminum paint.[1]

Table VI shows that, in the case of the General Electric refrigerating machine, the efficiency of heat transfer is improved 6½ per cent. by the application of white lacquer.

TABLE VI.

Effect of White Lacquer on Heat Dissipation.

	Bare Metal.	Lacquered.
Room temperature °F	100	100
Case top temperature °F	145	142.5
Refrigeration B.t.u./hr.	320	325
Motor input (151 watts) B.t.u./hr.	515	515
Total heat dissipated B.t.u./hr.	835	840
[11] Heat radiated B.t.u./hr.	225	250
[12] Heat convected B.t.u./hr.	610	590
B.t.u./hr. heat dissipated per degree rise	18.55	19.75
Relative efficiency of heat dissipation	100%	106.5%

[9] "Effect of Paint on Radiator Performance," *Journal of the American Society of Heating and Ventilating Engineers*, December, 1928.

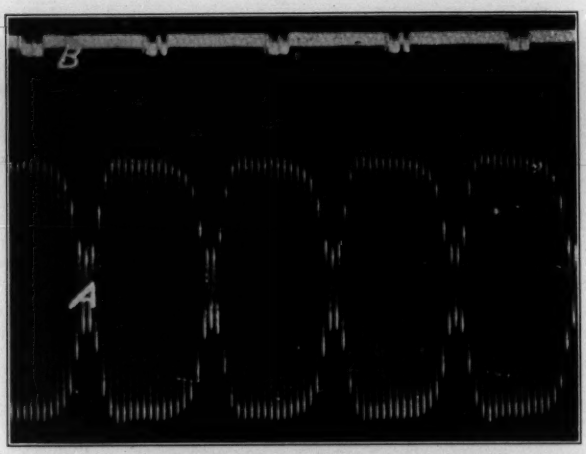
[10] "Effect of Bronze and Paint on Radiator Efficiency," *Electrical World*, June 22, 1911.

[11] Radiation emissivity of oxidized steel plain surface is about 0.70, and for a steel finned structure about 0.85. For white lacquer, the value is 0.90 to 0.95 with a plain surface.

[12] Convection is decreased because of lower temperature.

The study of the mechanical efficiency of the machine presented some very interesting problems. It was first necessary to develop a method of taking indicator cards in a small cylinder 1 inch diameter by 0.7 inch stroke, running at approximately 1,740 revolutions per minute. This work was done by a young student from the University of Minnesota who was spending a summer in our Research Laboratory.[13]

FIG. 29.



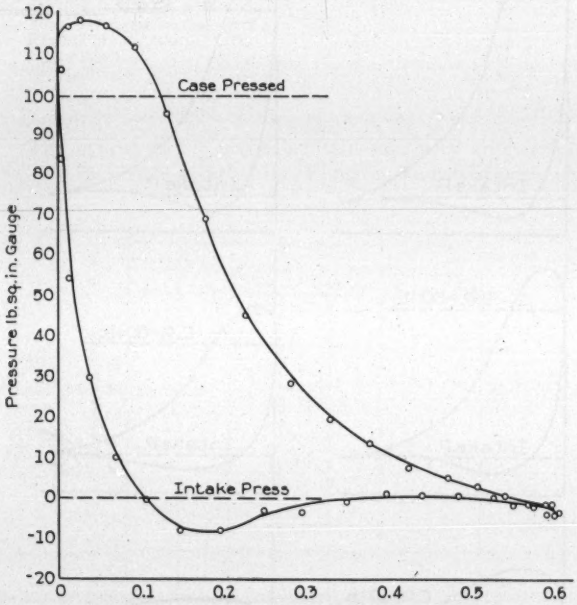
Indicator Card for 100 Lb. Case Pressure.
A = amplitude, indicates case pressure minus cylinder pressure;
B = contact at end of suction stroke.

Briefly, the method was as follows: The piston head was made of thin material which could flex under pressure, thus changing the air gap of a magnetic device built into the piston which was in principle similar to the old-fashioned magnetic telephone transmitter. Thus the flexure of the piston head could be measured on an oscillograph, as shown in Fig. 29.

[13] "Electrical Method of Obtaining Indicator Card of a Compressor," by M. E. Fiene, *Refrigerating Engineering*, March, 1928.

The oscillogram is plotted with time, which is proportional to angular movement of the crank, as the abscissa. In order to get a picture which was understandable, it was necessary to replot these ordinates against the motion of the piston as abscissa. This is done in Fig. 30. It can be noticed that

FIG. 30.

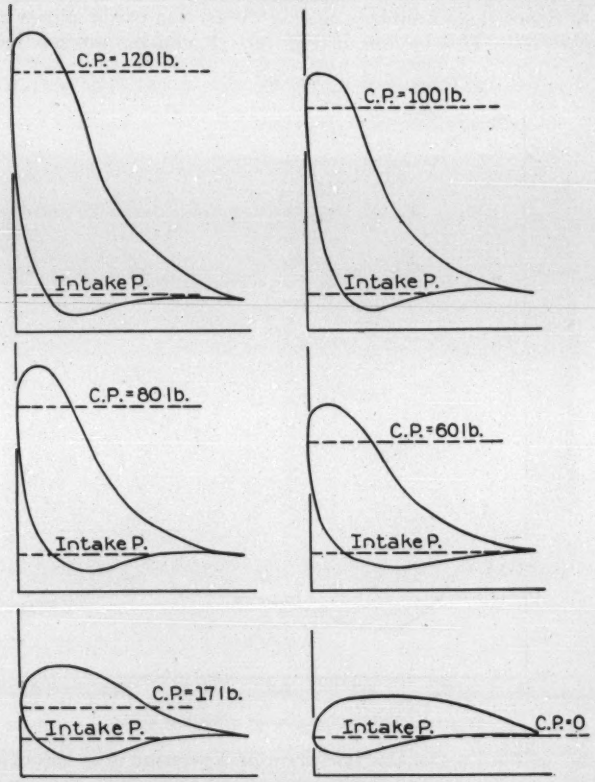


Compression Indicator Card Obtained by Electrical Method.

the card is a reasonable one, showing a pressure drop through the suction ports when the piston is at mid-stroke traveling at the highest speed, and showing a pressure rise at the discharge ports and re-expansion of the clearance volume. The reasonable shape of these indicator cards shows how efficiently the gas is sucked into the cylinder and forced out again, even at the high rate of 1,740 times a minute.

A whole set of cards for different pressures is shown in Fig. 31.

FIG. 31.



Comparison of Indicator Cards at Different Case Pressures.

Of course, the power represented by the indicator card is not equal to the motor input. All small devices of this kind are really quite inefficient. A very rough estimate of the

distribution of losses with the refrigerating machine operating in a 70° F. room with 70 lb. per square inch sulphur dioxide pressure and an oil temperature of 145° F. is shown in Table VII.

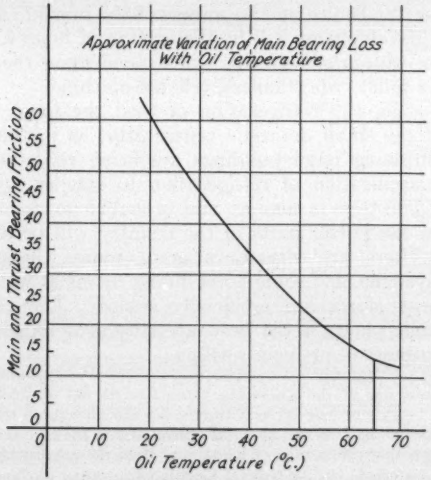
TABLE VII.

Distribution of Power in DR-2 Refrigerator.

Work on gas (indicator card)	50 watts
Circulation of oil	6 "
Main and thrust bearing friction	14 "
Friction of reciprocating parts	10 "
Motor losses	60 "
Oil conditioner	10 "
Total	150 watts

The figures in the preceding table are very approximate because they vary greatly, depending on the conditions under

FIG. 32.



which the machine is operating. For instance, the temperature of the oil bath makes a big difference in the main bearing loss. Fig. 32 shows this variation. At about 150° F., this loss is one-quarter what it is at 70° F. In the General

Electric refrigerating machine, we have a little 10-watt electric heater which keeps the oil bath warm even when the machine is shut down. This curve illustrates the fact that the power consumed by this little heater is not all lost. The heater takes only about 10½ watts, while there is a possible saving of about 30 or 40 watts for the first part of each cycle when the machine first starts up. However, this heater was not put in for this purpose, but as an oil conditioner to keep the sulphur dioxide boiled out of the oil, in the same way that some high-priced automobiles have oil conditioners heated from the exhaust to keep the volatile gasoline boiled out of the lubricating oil.[14]

HOUSE COOLING.[15]

The development of the domestic refrigerating machine for cooling food is only one of the things which refrigeration can do for the health and happiness of the human race. The next big development will be the cooling of houses. In this field also, widespread success will depend upon the development of a quiet, vibrationless, reliable machine.

Just as in the refrigeration of food the large ice plant preceded the small domestic refrigerator, so in this field of air conditioning large buildings are being refrigerated first and the application of refrigeration to smaller houses will follow. The time is coming, and probably not far off, when houses in the hotter parts of the country will be artificially cooled. There are already a great many theaters with cooling systems, and some hotel dining rooms as well as large department stores are artificially cooled. The cooling of these public places is the best advertisement imaginable for the advantages of artificial cooling.

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[14] At least one of the automobile manufacturers has abandoned the oil conditioner because on long drives it became hot enough to burn the oil. This is, in my opinion, no reflection upon the general idea of the oil conditioner, but only indicates that the method of taking heat from the exhaust had not been sufficiently perfected. In the General Electric refrigerating machine, the oil is heated by an electric heater so designed that it cannot attain a temperature high enough to injure the oil.

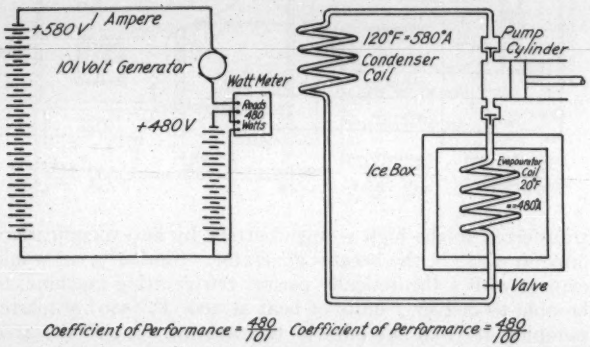
[15] "Cooling Homes—a Field for Refrigeration," by A. R. Stevenson, Jr. Published in Report of Refrigeration Committee 1926, American Gas Association, pages 23–26.

HOUSE HEATING.

Lord Kelvin [16] suggested many years ago that refrigerating machines could be used to advantage to heat houses in winter. Refrigerating machines are really heat pumps and may be used to pump heat into a house as well as out of it.

It is likely that in southern climates the refrigerating machines installed for the purpose of cooling the houses in summer may also be used to heat the houses in winter. Preliminary figures seem to show that a system large enough to refrigerate a house properly in New Orleans would be much larger than necessary to heat the house in winter.

FIG. 33.

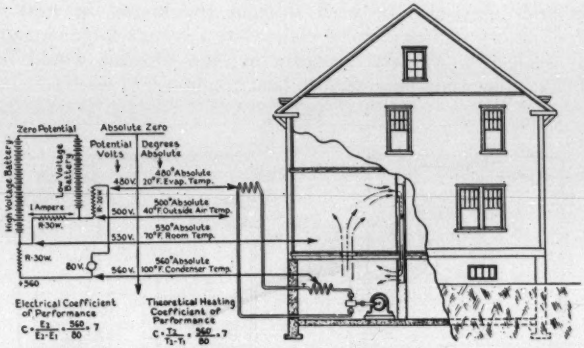


This scheme of heating houses with refrigerating machines will probably be impracticable in the colder climates where very low temperatures are encountered; but in the south, if electrical heating of homes is to be considered, this method of doing it by means of refrigerating machines cannot be overlooked. Approximately four times as much heat on the average can be delivered to a house by a refrigerating machine pumping heat from outside than by using the same amount of electric power in resistance heating units.

[16] "Economy of the Heating or Cooling of Buildings by Means of Currents of Air," by Lord Kelvin, published in the *Glasgow Philosophical Society Proceedings*, Vol. III, December, 1852.

This apparent 400 per cent. efficiency can best be explained by an analogy. Consider a 100-volt booster generator which is used to transfer an electrical charge to a 560-volt storage battery from a 480-volt battery. If the current flows at the rate of 1 ampere, it is obvious that 560 watts are being

FIG. 34.



transferred to the high voltage battery by an expenditure of only 80 watts in the booster generator. Similarly, we would expect, with a theoretically perfect refrigerating machine, to be able to deliver 7 units of heat at 100° F. (560° absolute) pumping it from an outside temperature of 20° F. (480° absolute), by an expenditure of one unit of work.

The broad philosophic aspects of the heating and cooling of houses are very interestingly discussed in a paper by Ellsworth Huntington,[17] describing the northward march of civilization as the human race learned to heat houses. In the last paragraph he says:

"Still another great step may follow in due time; we may conquer heat as well as cold. In the far future such a conquest may send the centers of civilization back once more into warmer regions. Thus far practically every invention of the kinds here discussed has been directed against low temperature. . . . Practically nothing has yet been done to conquer heat in the same way. The inevitable result is that tropical countries have remained at a low level, and have

[17] "Temperature and the Fate of Nations," *Harper's*, August, 1928.

rarely made any important advance in civilization except as new ideas are introduced from cooler regions. Yet in the far future there is no apparent reason why the conquest of heat as well as cold may not send the centers of civilization back once more toward the warmer regions where they started long ago."

This quite impressively indicates the effect which this fundamental science of heating and cooling has and may have on the progress of civilization.

Photography in the Infra-red Region of the Spectrum. M. CZERNY. (*Zeit. f. Physik*, Vol. 53, p. 1.) Photographic plates by the application of dyes have been made sensitive to infra-red light so that they can be used for waves about .001 mm. long. Since thermal methods detect waves 400 times as long it is seen that a very long stretch of the spectrum cannot be photographed. Optical investigation can, however, be extended to about .0017 mm. by the use of a zinc sulphide screen that is fluorescing. Infra-red light falling upon a portion of this causes it to emit its light at a more rapid rate than ordinarily so that soon it seems darker than the rest of the screen. Thus a dark line on the screen means a bright line in the infra-red spectrum.

The author raises a fundamental objection to the possibility of extending photographic methods to any considerable distance into the infra-red. It must be remembered that all the objects in the room with the plate are radiating as well as the source of radiation under investigation. In the black radiation corresponding to the temperature of the room there are few quanta that fit wave-lengths of .001 mm. or less but there is an enormous number for a wave-length of .004 mm. In fact the relation is about $1 : 10^{15}$. The plate would therefore get fogged by the general radiation from its surroundings.

Accordingly a different type of optical process is brought forward in which the registration of long waves is not interfered with by the unavoidable black radiation of adjacent bodies. A substance such as camphor or naphthalin, possessing at room temperature a considerable vapor pressure, is spread in a thin white film and placed in a closed space saturated with the vapor. When the infra-red spectrum falls on the film, there will be sublimation at the place where a bright line is incident, because the temperature rises owing to absorption. The thickness of the film grows less or is reduced to zero. When the radiation ceases the film retains its thickness unchanged and thus a permanent record is obtained. Naphthalin showed itself better fitted than camphor. A pressure of .2 mm. mercury was suitable. A photographic reproduction of the appearance of the naphthalin film is given as it was after infra-red radiation had fallen on it for 20 minutes. Four lines in the region from .0015 to .0035 mm. are seen. An exposure of 90 minutes melted away a patch of the deposit in the short wave-lengths of the incident spectrum but as compensation there appears a line at about .006 mm. The source of radiation was a Nernst glower.

G. F. S.

REPORT ON THE WORK OF THE BARTOL RESEARCH FOUNDATION, 1928-9,*

MADE TO THE MEMBERSHIP OF THE FRANKLIN INSTITUTE

BY

W. F. G. SWANN, D.Sc., Director.

IN this particular annual lecture, the Director of the Bartol Research Foundation functions in the capacity of chief chef, and of maitre d'hotel. Having superintended the preparation of his various dishes, the problem remains of laying them before you in artistic manner. He cannot simply place them on the table in cafeteria fashion, and yet he is somewhat perplexed as to the order in which he should serve them to you. For while tradition has evolved some sort of sequence which is happily adapted to the purposes of the gastronomic appetite, she has so far evolved no such sequence for such dishes as I have to present this evening. Then, while the ordinary banquet calls for only one course of hors-d'œuvre to introduce whatever has to follow, my dishes are so diverse in nature, that each must have his own little course of hors-d'œuvre to make it appetizing, and in the preparation of these appetizing morsels, I am confronted with a sea of faces very familiar to me, very pleasing to my eye, very sympathetic and understanding, but with expressions suggestive of the fact that they are horribly reminiscent of the dainties which I served to them a year ago.

In order that I may bring home to as wide a group of my audience as possible, a picture of what we are attempting to do, I will ask those who are specialists in physics to bear with me for a period of a few minutes while I bring forth once more for exhibition a few of the bricks, cornerstones, and fundamental parts which go to build the universe, that structure whose architecture it is the function of the physicist to delineate. First we have the electron, the fundamental unit of negative electricity, a thing so small that ten million million

* Presented at the Stated Meeting held Wednesday, April 17, 1929.

of them placed side by side would take up but the space of a centimeter. Then we have the proton, the fundamental unit of positive electricity, a thing about two thousand times smaller, and also about two thousand times heavier than the electron. Out of these two entities of nature's structure we have sought to construct a picture of what has turned out to be the most capricious thing in all nature, not excluding the things which live, or even the female sex thereof, the atom. According to the views of the immediate past, at any rate, an atom is a little solar system in which electrons rotate about a central nucleus in definite orbits as planets rotate about the sun. This nucleus contains nearly the whole of the mass of the atom, and all of the protons.

Light we regard as a wave motion travelling through space, and a definite frequency of vibration, a definite wave-length in the all pervading medium, corresponds to each particular color of the rainbow. The waves of wireless telegraphy, the waves which constitute heat, those which correspond to light, the waves which we associate with ultra-violet light, X-rays, the gamma rays from radioactive substances, and finally the cosmic rays originating in inter-stellar space, we regard as all of the same fundamental character, differing from each other only as regards the length of the wave.

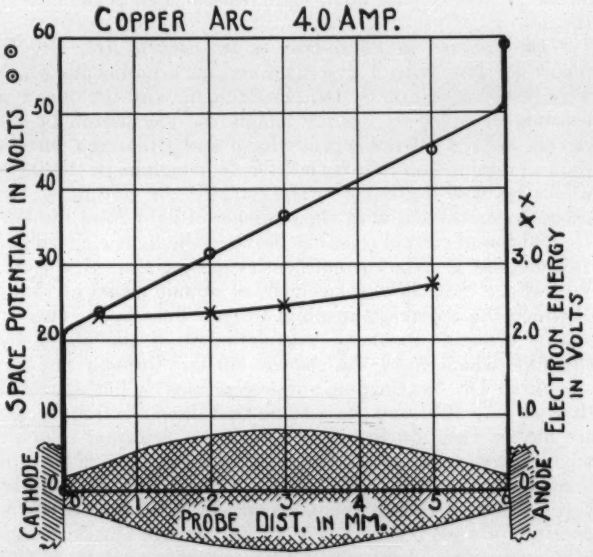
We have come to think that under ordinary condition no light is radiated from an atom, but that if an electron falls from an outer orbit to an inner one, then light is produced of a frequency depending upon the change of energy which the electron experiences in the fall. If the change of energy is very great, as is the case when an electron falls from regions outside of the atom to regions near the center, the wave-length of the radiation emitted is very small, and we associate it with X-rays. In general, the electrons from an atom are in stable orbits from which they do not tend to experience any falls of this kind, but by various means we may hurl some of them into outer orbits, or we may hurl them completely out of their atom. When they return, or when others fall into the atom to take their places, we obtain an emission of radiation. We believe that the light produced in the electric arc, for example, is obtained by hurling an electron from one

of the stable outer orbits of the atom to a still larger orbit and then allowing it to fall back. By more violent action we may hurl an electron right out of the atom, leaving the latter positively charged and again light will be produced by the return of the electron to the former orbit. The light produced in this way is characteristic of the electric spark, where the agency for hurling the electrons out of the atom is, on account of the greater electric field, more drastic than is the case in the arc.

Investigations on Phenomena in the Electric Arc.—In my report for last year, I described certain experiments which were being carried on by Dr. Nottingham, with the object of learning as much as possible about the mechanism of the electric arc. I will not repeat what I said a year ago, further than to remind you that we left Dr. Nottingham at the stage where he was beginning to investigate the nature of the processes associated with the emission of light from the arc. He had found certain relations between the light emitted per unit volume, and the current density passing through the arc. We believe that the displacement of atomic orbits in virtue of which the atoms are inspired to emit light in the electric arc, is brought about by bombardment of the atoms by electrons which carry the electric current through the arc; and, from Dr. Nottingham's investigations, it has appeared that we are called upon to assume that these electrons in the arc have a very much greater velocity of agitation than we might have supposed at first sight. They have a sort of temperature which is very high compared with that of the vapor which surrounds them. You will recall that the temperature of a gas is determined by the average kinetic energy of its molecules. I remember once watching a swarm of flies moving backwards and forwards in a random manner which appeared very similar to the motion which we associate with molecules, and I took occasion to calculate the average kinetic energy of those flies in order to see what sort of a temperature they would correspond to. I found that they were living up at the horrible temperature of about three million million million degrees Centigrade. Of course, the flies were really not at this temperature, but the velocity producing an apparent temperature was there. So, it

appeared that these electrons in Dr. Nottingham's arc were moving with a velocity characteristic of a very high temperature. Using a direct determination of the velocity of the electron in the arc, by means of a method designed by Dr. Langmuir for such purposes, Dr. Nottingham was able to show that the velocities which were required from his optical

FIG. 1.



Distribution of potential and electronic energy along the copper arc.

consideration, really did exist. During the present year, Dr. Nottingham has pursued further this matter concerned with electron velocity in the arc. He has also investigated the way in which the potential changes as we pass along the length of the arc. He has extended his investigations to the light omitted by the individual spectrum lines and has reached certain interesting conclusions which I shall cite in a moment or two. I have no time to enter into the details of the experi-

ment, and I must deal only with the results.[1] Fig. 1 represents the conditions found at different points along the length of the copper arc. The average energies of the electron are plotted vertically and are expressed as the number of volts which an electron would have to fall through in order to obtain the corresponding energy. The shaded part gives a general idea of the width of the arc stream at various points between the anode and the cathode. You will notice that in the neighborhood of the cathode and the anode, there is a very definite and sudden fall of potential. Most theories of the electric arc require the existence of such a fall of potential, and require that it shall be intimately related to the ionization potential, i.e., the potential through which an electron must fall in order to acquire enough energy to remove another electron from the atom. Our knowledge of such relationships has been delayed on the one hand by lack of knowledge of the ionization potentials, and on the other hand by imperfections in the method of determining these drops of potential at the cathodes. The latter imperfections are removed by a proper application of Langmuir's method of measuring these potentials, and in the experiment of Dr. Nottingham, we see that for the copper arc, the cathode drop of potential is just over 20 volts and is in excellent agreement with the known double ionization potential of copper vapor which is 20.5 volts. The double ionization potential is the potential corresponding to the removal of an electron from an atom which has already lost one electron. Thus these experiments crystallize for us in definite form the starting point for our theories and provide us with a relationship between cathode fall of potential and the critical potentials for the vapors concerned. Dr. Nottingham has carried out these experiments for an arc in copper, in which the agreement is as I have stated, in cadmium, in which the cathode fall was very nearly equal to 8.9 volts, the single ionization potential of cadmium, in thallium in which the cathode fall was slightly higher than 6.08 volts, the ionization potential for that vapor, and in carbon, in which

[1] The complete account of these investigations is published in the JOURNAL OF THE FRANKLIN INSTITUTE: "Probe and Radiation Measurements in the Copper Arc," published in Vol. 207, March 1929; and "Probe Measurements in the Normal Electric Arc," published in Vol. 206, July 1928, by W. B. Nottingham.

the cathode fall was 5 volts, which is sufficiently well in agreement with the value 4.4 volts of the ionization potential of the cyanogen molecule. Referring again to Fig. 1 you will see that there is a distinct fall in potential at the anode. For copper, this amounts to about 10 volts, for cadmium 1 volt, and for carbon 16.5 volts. The anode drop is not so characteristic of any special quantity associated with the theory of the arc, as is the cathode fall, however. You will notice that, through the length of the copper arc the potential rises uniformly. This feature is characteristic of all of these metallic, or monatomic arcs, and calls for no more drastic assumption than those of uniformity of conditions as regards the state of ionization of vapor throughout the length of the arc. The average electronic temperature associated with the various arcs are about 6000° C. for cadmium, 8000° C. for thallium, and 19,000° C. for copper.

It is obviously a matter of fundamental interest to inquire as to the origin of the apparent temperature of these electrons. If the electrons moved entirely freely between the anode and cathode, the electric field would of course accelerate them so that their velocity would increase more and more as they travelled along their path. The fact that the velocity is practically constant over the length of the arc stream is indicative of a mechanism which is able to absorb energy from the electrons at an average rate equal to that at which energy is given to them by the field. If the impact of the electrons with atoms and molecules were perfectly elastic, the electrons would lose very little energy to the molecules and, consequently, their velocity would increase from cathode to anode in very much the same sort of way as if there were no collisions at all. Now, taking the copper arc for example, Dr. Nottingham observed that the average temperature of the electron corresponds to the velocity they would obtain in a fall of potential of between 2 and 2½ volts. We could understand the existence of this apparent temperature, if there were some mechanism which rapidly absorbed the energy of electrons directly they reached a value greater than that corresponding to about 2.25 volts, for then the field would do its work in bringing them up to this temperature after which they would, as it were, commit suicide. Now,

Dr. Nottingham has pointed out that one of the electron transitions that is possible in the copper vapor atom is just such as to absorb between 2 and 2.5 volts, so that his thought is that the energy of the electron is limited by their being unable to attain a velocity higher than that at which they would be able to impart energy to the atom by causing a transition of the kind to which I have referred.

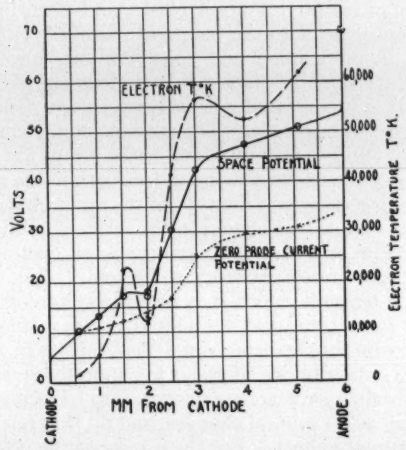
Further light is thrown upon this matter when we come to consider the laws which govern the emission of light from the arc, and here Dr. Nottingham has extended his earlier investigations to measurements of the intensity of the actual spectrum lines obtained from the arc. He has determined, for the various lines, the relation between the intensity of light emitted, and the density of the positive ions in the arc, this density of positive ions being practically equal to the density of the electrons, as may be readily seen from the fact that field through the arc is uniform. The results of this portion of these investigations lead to some greatly interesting conclusions. Thus, for the light of wave-length $\lambda = 0.00003274$ cm., and $\lambda = 0.00003248$ cm., the intensity varies in proportion to the square of the electron density. For the lines, $\lambda = 0.00002824$ cm. and $\lambda = 0.00002766$ cm. it is proportional to the cube of the electron density. For $\lambda = 0.00004065$ it is proportional to the fourth power. We obtain a consistent interpretation of these results if we assume that atoms can receive energy from the electrons in successive amounts, storing them up, and emitting them from time to time according to the following considerations. Suppose that for simplicity we consider what would happen if an atom could exist in several states which we will label 0, 1, 2, 3, 4, according to the amount of energy required to raise it to those various states. Then, the rate at which atoms were brought into the state at 1, would of course, be proportional to the electron density since that is the factor which is responsible for determining the number raised to this state per second. The atoms in the state 1 will be continually passing out of it, for example by radiation of their energy in the form of light; and, if this were the only means by which they passed from the state 1, it is obvious that since a condition of equilibrium would be obtained when the number

entering that state was equal to the number leaving it, the light intensity would be proportional to the electron density. On the other hand, a number of those which were in the state 1 will leave that state, not by emitting light, but by being thrown by some electron impact into the state 2. The number which experiences this calamity per second will be proportional to the number in state 1, and again to the electron density. Since the number in the state 1 also depends upon the electron density, and since it can be shown to be very approximately proportional to the first power of that density, it will be seen that the number which enter the state 2 per second will be proportional to the square of the electron density. Hence, in the state of equilibrium, where the number leaving that state per second is equal to the number entering it, the number leaving it per second will be proportional to the square of the electron density, and to the extent those leaving the state do so by light emission, the corresponding light intensity will be proportional to the square of the electron density. Then we may consider that some of the electrons in state 2 are carried to the state 3 by electron impact and the emission of light by these results in an intensity proportional to the cube of the electron density, and so on. A detailed consideration of these factors, of which the foregoing forms only an approximate picture, leads to conclusions in beautiful harmony with the experimental results, and incidentally, these conclusions confirm and, of course, considerably extend, the idea as to the electrons losing energy by promoting transitions between the various energy states of the atom, and so they confirm the idea that this factor is the one which determines the state to which the electric field is able to build up energy of agitation in the electrons.

When we turn to the carbon arc, we find considerations considerably different from those presented by the metallic arc. Instead of having a practically constant temperature throughout the length of the arc from cathode to anode, we see from Fig. 2, that there is a very fluctuating temperature, and then the potential instead of increasing uniformly from one end of the arc to the other, undergoes the rapid fluctuations indicated also in Fig. 2. The situation is very similar to that which one obtains in the case of discharge showing

striations in a rarified gas; and as a matter of fact, striations are visible in this particular arc. A consideration of the apparent electron temperature shows that, contrary to what we find in the case of the metallic arc, the kinetic energy of the electrons is sufficient to enable them to ionize the cyanogen molecule at nearly all parts of the arc. In fact, while, in the

FIG. 2.



case of a metal arc, the electron energy is only sufficient to raise the atoms from one energy state to another so that ionization can only be reached as a result of many successive contributions of energy, the electrons in the carbon arc have enough energy to ionize the atoms at one blow. At about 1½ mm. from the cathode they have already attained this energy, and here ionization can take place with the result that there is a sudden drop in the electron's temperature, or energy, as indicated at the corresponding point on the curve. The complete story with regard to the carbon arc has not yet been worked out, and it will be of interest to see how the intensities of the various lines depend upon the electron density for this particular arc.

Time does not permit me to enter into the complete details of Dr. Nottingham's experiment; I might however, refer to one or two isolated features which have developed during the course of the work. Ordinarily, one would measure the intensities of spectrum lines by allowing them to fall upon a photographic plate, and then measuring the density of the image. This procedure was not very satisfactory for several reasons. In the first place the procedure necessitates laborious calibration of the photographic plates, and attention to many matters concerned with the temperatures of development and so forth. A more important consideration, however, arises from the fact that it is impossible to keep the arc steady in the sense that it continually flows between two definite points on the anode and cathode. The arc continually changes from one spot to another in jumps, and these jumps are associated with changes of current density and so forth in the arc stream. Then there is a change in the type of the arc, a change brought about, for example by a change in the surface conditions at the cathode. For any one of these types of arcs, there is a consistent and important story to be told, but in comparing the various features which it is of interest to compare, it is obviously important that we should compare them for the arc under exactly the same conditions. Now in the photographic process, a period of about five minutes is necessary in order to obtain a satisfactory photograph. During this time, the arc may suffer several changes, and all that one obtains is a sort of average effect. For these reasons, Dr. Nottingham has adopted a method which involves the practically instantaneous measurements he desires. The procedure was to allow the light from the slit to pass through a monochromatic illuminator and fall upon a slit through which it passed and fell upon a container filled with a saturated solution of fluorescent material. The intensity of the fluorescent light was then measured by means of a photoelectric cell. This, as you will recall is a device in which the light falls upon a sensitive potassium surface, from which it emits electrons at a rate which can be measured and which forms a measure of the intensity of the light falling upon the surface. Under these conditions when the arc suddenly changes from one form to another there is a very distinct observable change in

the measurement so that one need never have any doubt as to which type of arc he is really studying.

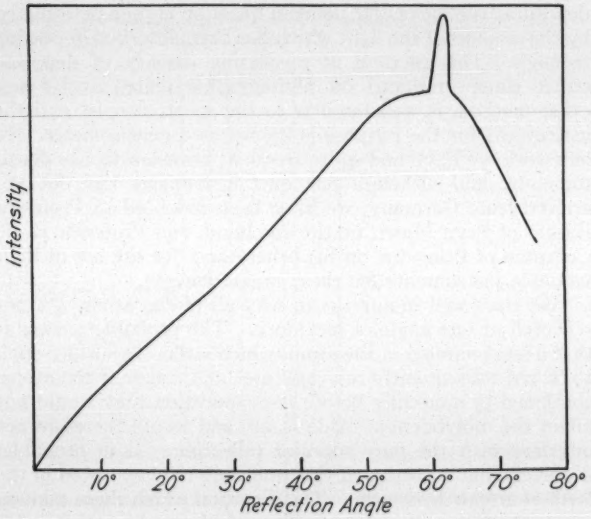
Experiments on the Reflection of Atoms from Crystals.—In the last few years, our notion as to the nature of atomic processes has undergone one of the most drastic changes that has ever been experienced in any branch of physics. Twenty years ago everyone was apt to regard light as a wave motion in the all pervading ether, and to regard electrons as small particles of electricity as truly representative of what we would wish to call a particle as anything under heaven could be. And then, there arose a set of phenomena which seemed to require that we think of the propagation of light as taking place not by waves but by a process more analogous to that of the emission of bullets of light from the illuminating source, these bullets possessing the property of carrying their energy and momentum in a very concentrated form. And so we had to face the unsatisfactory situation of being compelled to regard light as waves for some purposes and as corpuscles for others. And then, to make matters worse, the electron itself, which everyone had always thought of as a corpuscle began to show in certain cases, a behavior which could only be reasonably expected of a wave. If a beam of light or any wave radiation for that matter, be reflected from a group of parallel equidistant lines ruled upon a smooth surface, the waves will be reflected in a rather characteristic way. In the first place there will be a beam of waves which comes off at an angle to the normal to the surface equal to the angle at which the original wave is incident. Then there will be a number of other beams which come off at different angles, and we can understand this phenomenon provided that we take into account the wave-like nature of the wave itself. A somewhat similar situation exists in connection with the reflection of waves from any regularly arranged set of points. According to our old notion, the shooting of a parallel beam of electrons onto a surface would be like shooting a beam of shot onto an evenly piled area of cannon balls, for the molecules of the surface are very large in comparison with the dimensions of the electron. We should expect no regular reflection from the surface, but merely a heterogeneous scattering caused by the fact that the electrons struck the cannon

balls at all sorts of different angles. What we find, in fact, is that when a homogeneous beam of electrons strikes a crystal surface, the electrons come off in a definite direction, which direction is the same as that which would be taken by a beam of X-rays which were incident at the same angle as the electron beam and which had a wave-length equal to h/p when p is the momentum of the electrons, and h is a constant well known to physicists as Planck's constant. Now I do not wish to twist your imagination too much by asking you to imagine that an electron can masquerade as a wave and as a corpuscle at the same time, and I will go straight to the point of suggesting that the thing which is characteristic of the difference between our knowledge of the situation today and the situation as it appeared to us five years ago as regards the electron, concerns not so much its nature as the way in which it moves. Five years ago in thinking of the motion of an electron, the situation presented to our view was that of a particle moving freely in space until controlled by forces which came into play in the immediate vicinities of the atoms only. Now it seems that its motion is determined otherwise. With each electron we have to imagine a plane wave, not a wave of light, but a wave which does not affect directly any of our senses. This wave is reflected from surfaces and is twisted by passage through matter in a manner crudely analogous to that familiar in the case of waves of light passing through non-homogeneous media. We suppose that electrons follow this wave in a sense which, in simple cases, at any rate, corresponds to the electrons assuming a direction of motion parallel to the normal to the wave surface. If the wave becomes split into two or three different waves at the surface of a medium, the probability that the electron will follow one or the other wave is determined by the relative intensities of the waves. Now, insofar as atoms have in times past shown the characteristics of bullet like things when in motion, it is of interest to inquire whether they, also may be guided in their motions when they come near to each other, not by forces in the old sense of the word, but rather by wave systems, in the same way the experiment has suggested that the electron appears to be guided.

One of the simplest of all atoms is the atom of hydrogen,

and last year I described how Dr. Johnson was investigating the reflection of hydrogen atoms from a crystal of rock salt. At that time, Dr. Johnson had just succeeded in showing that a beam of hydrogen atoms was actually reflected from the crystal of rock salt in such a manner that the angle of reflection was equal to the angle of incidence. Or perhaps it would be better to say that an appreciable portion of the beam is reflected in this manner. Fig. 3 represents the intensity of a

FIG. 3.



stream of atomic hydrogen reflected from a rock salt crystal for an angle of incidence equal to 60°.[2] You will observe that in addition to the general reflection at all sorts of angles, there is a markedly enhanced reflection represented by the little peak at the angle of reflection equal to the angle of incidence.

[2] The details of this work have been published in the JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 206, Sept. 1928—"The Reflection of Hydrogen Atoms from Crystals," by Thomas H. Johnson.

I may say that the method of detecting the beam of atomic hydrogen is to allow it to fall upon a glass plate which is coated with molybdenum oxide. The atomic hydrogen turns this substance blue, and the intensity of the beam falling on any particular portion of the plate is proportional to the darkening of the plate at that particular point. The intensity of the darkening is measured by taking the plate and allowing a beam of light to pass through it and fall upon a thermocouple, a photoelectric cell, or some other convenient apparatus for measuring its intensity. The density of the deposit at the particular point in question is then determined by the amount of the light which has been absorbed in passing through. This method of measuring density of deposits, either those produced on photographic plates or by any other method, is well familiar to the spectroscopist and the instrument for the purpose is known as a densitometer. In our work we have had quite frequent occasion to use densitometers, and although our own instrument has not yet arrived from Germany, we have been indebted to Professor Barnes of Bryn Mawr, on the one hand, and Professor K. T. Compton of Princeton on the other hand, for the use of their valuable instruments for these measurements.

We may well inquire as to why all of the atoms are not reflected at one angle of incidence. The probable answer is that a large number of the atoms which strike the surface stick to it and subsequently re-evaporate. Of course if the atoms combined to molecules before re-evaporation they would not affect the molybdenum oxide at all, and would therefore not interfere with the pure specular reflection. It is probable, however, that a portion of the atoms are re-evaporated in the form of atomic hydrogen. The direction which these take on re-evaporation will of course, be a random one, and it is for this reason that we obtain, in addition to the specular reflection, a large amount of apparently diffuse reflection. If the conclusions in this respect are warranted, we might well suppose that the ratio of the diffuse reflection to the specular reflection would depend upon the temperature as theoretical consideration would tend to show that the time which an atom of hydrogen could remain on a surface uncombined with one of its neighbors would be influenced by the temperature.

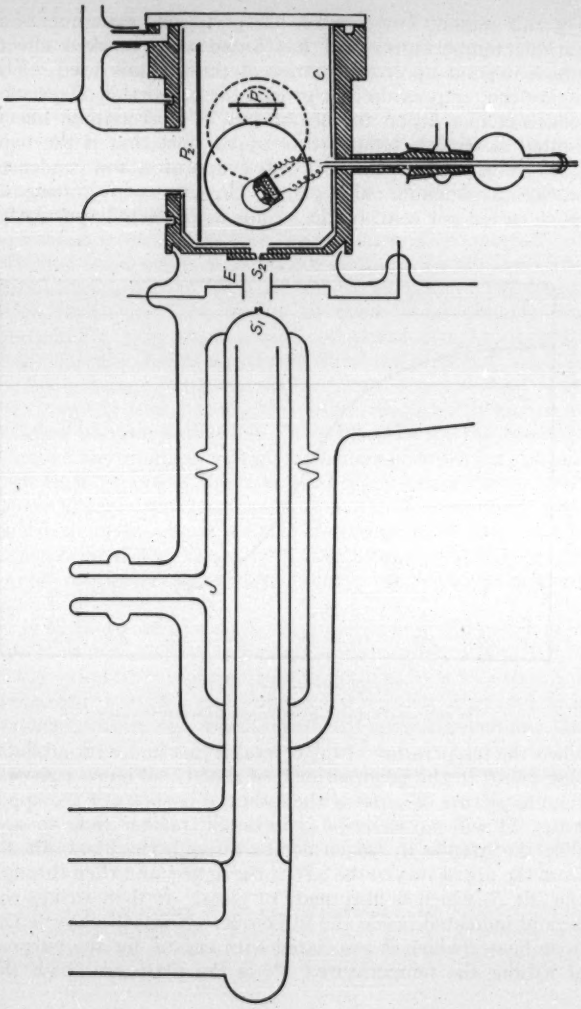
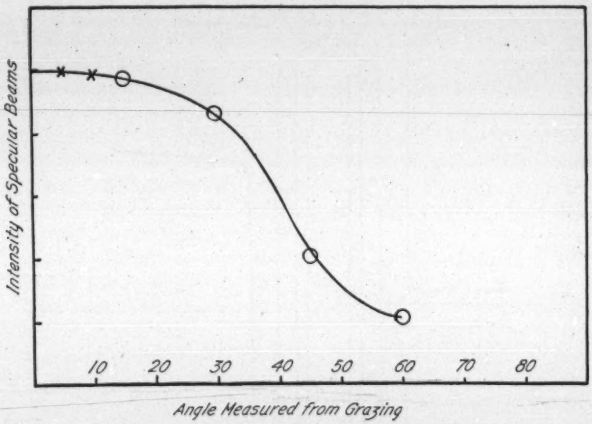


FIG. 4.

For this reason, Dr. Johnson has performed experiments at various temperatures and has found very marked effects which depend upon the nature of the crystals used. The higher the temperature, the greater the proportion of specular reflection in relation to the diffuse. Unfortunately, one is limited as regards temperature by the fact that if the temperature is too high the rock salt evaporates, and condenses on the molybdenum oxide plate. However, near grazing, as much as ten per cent. of the atoms are reflected specularly,

FIG. 5.



The variation of the intensity of the specular beams with angle.

when the temperature of the crystal is just under its sublimation point, in the neighborhood of 400° C. Figure 4 gives a general picture of some of the essential portions of the apparatus. I will not describe it in detail, further than to say, that the atomic hydrogen comes through the glass slit S_1, from the apparatus to the left of the figure, and then through the slit S_2 which is also made of glass. It then strikes the crystal indicated inside the full circle. You will observe the little heater which is associated with crystal for the purpose of raising the temperature. P_1 is the plate on which the

molybdenum oxide is placed. Great precautions are necessary as regards the production of the vacuum, the absence of grease, etc., for details of which I must refer you to Dr. Johnson's paper on the subject. By taking a number of curves such as those of Fig. 3 at the different angles of incidence, and making suitable measurements on the protuberances above the main bodies of the curve, it is possible to compare the intensity of the specular reflection at several different angles of incidence. Data such as these have considerable importance because the variation of the intensity of reflection with angle of incidence contains within itself the story of the nature of the action of the crystals on the waves which strike it. The results of these measurements are shown in Fig. 5, by which it will be observed that the intensity of the specular beam is greatest when the reflecting angle is nearest grazing. This particular curve was obtained with the crystal heated just under the temperature at which sublimation became noticeable. The intensity of the specular beam at any angle is greater and more independent of the angle of incidence at lower than at high temperatures. Dr. Johnson has proposed an explanation of these phenomena with regard to temperature, and to variation of density at the angle of incidence, based upon the lattice structure of the crystal, for the details of which I must refer you to the original paper.[3]

Now there are two possibilities as regards the action of a crystal as a grating. It may act as a surface grating, that is to say, a number of lines, ruled parallel to each other on a plane, or it may act as a volume lattice, that is to say, as a number centers of reflection distributed throughout the crystal. It is in the latter sense that the crystal acts towards X-rays. Now the theory of electron waves teaches us that the wave-length of the wave associated with any electron is proportional to the reciprocal of its velocity. Moreover, we know that while in the case of the surface grating, waves will be reflected at the angle of reflection equal to the angle of

[3] The complete account of this work is published in Dr. Johnson's Article, "The Reflection of Hydrogen Atoms from Crystals: Intensity Measurements of the Specularly Reflected Beam," JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 207, May 1929.

incidence, whatever may be that angle of incidence, and whatever the wave-length may be, in the case of action as a volume lattice, if we fix the angle of incidence, there is only one wave-length which is capable of being reflected at the corresponding angle. Thus, if the crystal acts like a volume lattice, we should expect that the specularly reflected beam would be composed of atoms, of one velocity instead of a heterogeneous mixture of velocities such as is to be found in the original beam on account of the temperature distribution of velocities in the original gas. If the crystal does act as a purifier in the matter of velocity, we should find that after reflecting the specularly reflected beam from a second crystal at an angle equal to that for the first crystal, a very much larger percentage of reflection occurs. Dr. Johnson has carried out an experiment of this kind,[4] reflecting the atoms from two crystals, and the conclusions at which he has arrived is that the crystal does not act as a three-dimensional grating, but as a plane. It would of course be very satisfactory if one could obtain not merely the specular reflected beam, but also those of higher order of diffraction. Owing to the temperature distribution of velocity in the atoms, however, and the consequent fact that the original beam of electron waves is a mixture of all sorts of different wave-lengths, it is practically impossible at the present stage to hope for the detection of these secondary beams because, while the specularly reflected beam is to be found in one direction for all wave-lengths, the second and higher order of beams occur at different angles depending upon the wave-length, so that we cannot expect more than the equivalent of a rather diffuse reflection as regards these higher orders.

The Excitation of Atoms by Electron Impact.—As I have implied, the emission of light by an atom suggests to our thoughts a number of considerations as to the details of the process. First we have the atom in what may be called its normal state, with its electrons revolving about its nucleus in their customary orbits. Then, as a result of some exciting cause, such for example, as an electron flashing into the atom as a comet might come into a solar system, one or more of these electrons may be disturbed from their normal orbits.

[4] Described in detail in the paper cited under footnote 3.

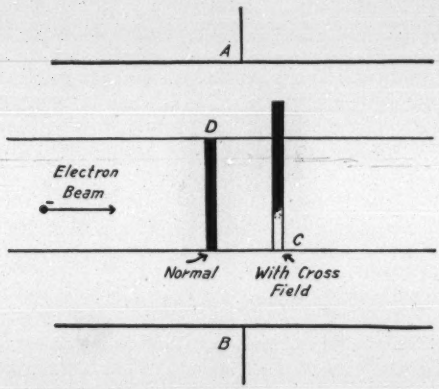
They remain in the new configuration for sometime and then fall back to their normal abode with the emission of light. We are naturally interested in the first place, in the nature of the catastrophe which causes the electrons to be hurled from their initial orbits. Is the catastrophe one in which only one of the electrons in the atom figures, or may two or more suffer a change of orbit at the same time? The so-called spark lines of the spectrum correspond to light emitted from atoms which have lost at least one electron. Is the action one in which an electron was hurled completely out of the atom, and another electron suffered a change in its orbit, both events occurring in a single act, or was it one in which one external electron hurled an electron from the atom to regions completely outside, while another electron from outside continued the good work by hurling some electron from one orbit to another? Then, another question of interest is that of how long these electrons remain in their unfamiliar orbits, in their excited states as we call them. You will see that a detailed knowledge of these considerations would give us an exact picture of just what was happening in the emission of light by the atoms, and so enable us to tell the complete story of what we actually observe. Dr. Maxwell has been interested in ferretting out the story of the atom's behavior in these connections.

At the time of my report last year, Dr. Maxwell had just obtained evidence that in the case of the so-called spark lines, that is to say, the spectrum lines which were obtained by the fall-back of an electron to its normal orbits in an atom which was itself charged, the act of charging the atom and of displacing the orbit took place simultaneously. He had also determined the orders of magnitude of the life of the atom in its excited condition. Since that time he has extended his investigation along these lines, has perfected the mathematical technique of analysing his results, and has been able to extract from his experiments much more information of a detailed nature.[5] I will not describe again the experimental

[5] The full account of this work has been published in two papers as follows: "Spectra of Mercury above the Ionization Potential" by L. R. Maxwell, *Physical Review*, Vol. 32, November 1928; "Determination of the Mean Life for the 4797A Spark Line of Doubly Ionized Mercury," by L. R. Maxwell, *Physical Review*, Vol. 32, November 1928.

arrangement of Dr. Maxwell's apparatus in detail. It will suffice for me to remind you that a beam of electrons, Fig. 6, is passed through a rarified gas, in the actual case, mercury vapor, and two plates *A* and *B* are placed one on each side of the beam, so that the beam itself may be subjected to an electric field between the plates *A* and *B*. The excitation of the atom by the electron beam results in a column of light coincident with the boundary of the beam itself, and it is possible to throw the image of a thin band of this light such as *D* onto the slit of our spectroscope, so that the light which

FIG. 6.

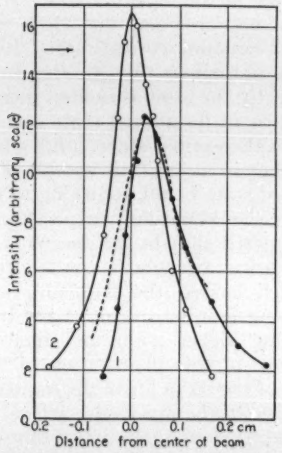


figures in the spectrum which we observe is the light which really comes from this little band *D* of the gas itself. If the atoms which participate in the production of light in the region *D* are uncharged, the electric field will have no effect upon them whatever. If, however the act of exciting an atom by one of the external electrons is first to hurl an electron out of it, and then raise another of its electrons to an excited state, that atom will move up under the influence of the electric field for some distance before it succeeds in coming back to its normal state with the emission of radiation. As I remarked in my report last year, Dr. Maxwell had suc-

ceeded in showing that the transitions associated with the spark lines did really take place in this manner as distinct from that associated with the arc lines which showed no effect of the electric field. Let us consider then, the case where the atom is charged and at the same time excited in the way I have described. If the atom should remain in the excited state for a certain definite time, then it would not be until the end of this time that we should obtain any light at all, and the bottom of the region in which light was emitted would be shifted up. In fact, the whole region would be shifted up by an amount corresponding to this time. In practise we could not expect the situation to be as simple as this, because directly the atom is excited there is a possibility that it may return to its normal state and there is simply an average life in the excited state, a life which is such that the greater number of atoms, but not all of them, live this long in the excited state before returning to normal. Under this condition, we should naturally expect that we should not obtain a mere upward shift in the spectrum line, but a distribution of intensity throughout the length of the line, a distribution which caused the darkening of the plate to commence by being infinitely weak at the bottom, rising to maximum at some higher point and then falling off still higher. The story of this distribution of intensity should give us the value of the mean life in the excited state provided that the mechanism of the process is such as I have outlined. On the other hand, there is a possibility that the process may occur in the second way which I have cited. The atom may suffer ionization by one electron, but no excitation, it will then move upwards under the influence of the electric field and it may then suffer a second collision, by an electron of the beam. After remaining in the excited state for some time it may then fall back with the emission of light. Under these conditions the variation of intensity of light along the line is quite different from that of the former case, and by measuring the distribution along the line it is possible to decide which of the mechanism is the correct one. For all of the spectrum lines which Dr. Maxwell has examined, he finds that the results are explained by the first and not by the second process. The kind of thing which he has observed is repre-

sented in Fig. 7. Here the intensity of the light emitted is plotted vertically, and the distance along the line from the point corresponding to the center of the field is plotted horizontally. The curves are obtained by means of a densitometer. The full curve to the left represents the distribution of intensity for an arc line, that is to say, a line which would not be affected by the electric field. Its purpose is to tell us the

FIG. 7.



Experimental curves showing intensity variation of (1) the 4797 spark line and of (2) an arc line which gives the width of the beam. The dotted line gives a calculated curve for (1) the spark line.

distribution of electron density over the electron beam, since it is not easy to obtain a uniform distribution of this quantity and it would be incorrect to assume that the distribution was uniform. We may say that this curve represents the distribution of intensity of spark lines in the absence of the electric field. When the field is applied we obtain the result shown in the right hand full curve. There is no difficulty in observing a shift of the maximum produced as the result of the application of the field. Now the theory of the process, into which I will not enter, since it involves calculation which would occupy the whole of the lecture, shows us

that on the basis of the first process which I have referred to, the distance between the two maxima is calculable entirely in terms of the electric field, the mass of the atom, the electronic charge and the mean life which we desire to obtain, so that by measuring the distance we can obtain the mean life in question. Having obtained this mean life it is possible to calculate how the distribution of intensity along the length of the line should vary. Of course, it would be very difficult to calculate accurately the results to be expected for a distribution of electrons in the beam such as correspond to the left hand curve. However, if we make the approximate assumption that this curve may be regarded as a triangle, at least for the upper regions, which are the most important in determining the shift of the maximum, then it comes out that the shape of the curve of distribution of intensity which we should expect to obtain is that represented by the dotted line. While it is not immediately obvious without going into much detail, I may say that the agreement of this dotted line with the experimental curve here shown is as good as can be expected within the limits of accuracy of the experiments. If we should imagine the process to take place according to the theory which I have called one, we should expect that the intensity at any portion of the line would come out proportional to the electron current density at the corresponding position in the beam. On the other hand, if the second type of action were the correct one, we should expect the intensity to come out approximately proportional to the square of the electron density of the beam. Experiment confirms the conclusion that the first power law is the correct one, and so the conclusion that the first mechanism is the one which actually takes place.

I will now cite one or two of the conclusions which Dr. Maxwell has drawn from these investigations. His main results are represented in Table I. The first column gives

TABLE I.

The Mean Life for the Mercury Spark Spectrum.

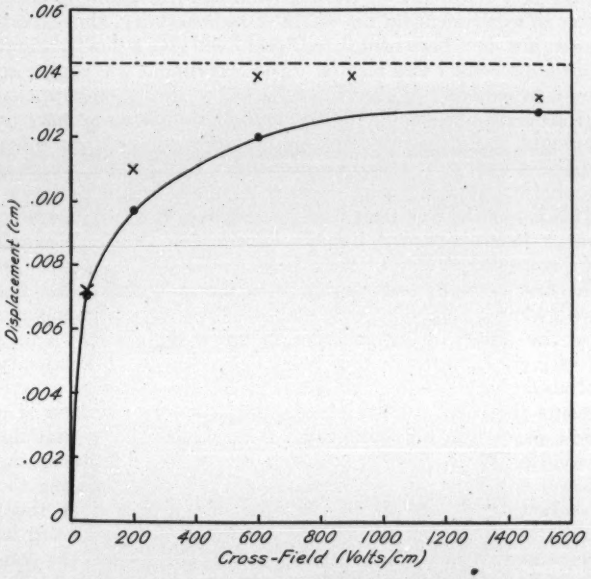
Wave-length of Line (Å).	Type of Ion Responsible for Line.	Mean Life (sec.).
3090	Hg^{++}	6×10^{-7}
3312	Hg^{++}	4×10^{-7}
4797	Hg^{++}	4×10^{-7}
2572	Hg^{+++}	8×10^{-7}
3114	Hg^{+++}	9×10^{-7}

the wave-length of the line concerned. The third represents the number of electrons which have been removed from the atoms which produced that line, and the last column gives the mean life of the excited state from which the atom returned to its normal state when it emitted the light. In the first place you will notice that the mean life is of the order of the one-millionth of a second. In the second place, you will notice what is perhaps a rather remarkable fact. The mean life appears to be about the same for the three cases where the ionic charge is two positive units, and again to be different from this, but about the same for the two lines in which that charge is three units. Thus it appears that the mean life is determined by the ionic charge, and is greater the greater the magnitude of that charge. A rough glance at the figures would suggest that, the mean life is roughly proportional to the square of the ionic charge. If this law represents the facts, the mean life corresponding to a singly charged ion would only be about 10^{-7} of a second, and would be almost too small for Dr. Maxwell to measure. As a matter of fact, that is why he hasn't measured it, and we have here a case where a failure to do an experiment supplies confirmation of the other results obtained and of the conclusion reached. This conclusion as to increase of mean life with the ionic charge is one which is contrary to what we might perhaps expect at first sight, for our general ideas have been to the effect that the greater the ionic charge the shorter the mean life.

I may perhaps cite one additional phenomenon as evidence of the validity of Dr. Maxwell's calculations in respect to the actual experimental results. One might think at first sight that the displacement of the maximum in Fig. 7 would increase with the field in such a way that if we had a very large field, the displacement would be very great indeed. However, the theory of the process shows that the effect of increasing the field is to bunch up the density in places and spread it out in others in such a manner that if we plotted the displacement against the field we should get a curve such as is given in the thick line in Fig. 8, so that even for infinitely great fields it would not reach to a greater distance from the horizontal axis than is represented by the dotted line. The distance of this dotted line is one-sixth of the width of the field. The crosses

represent the experimental results obtained with different fields and are in harmony with the theoretical conclusions to as good a degree as it is possible to expect from the experiments.

FIG. 8.



The success which has been obtained from this method so far has prompted Dr. Maxwell to continue these investigations for helium. A great amount of theory has been formulated with regard to the way in which transitions should occur in atoms, but it is only possible to apply theories to comparatively simple atoms like hydrogen and ionized helium. Hydrogen would be the simplest gas to use except that when one has removed an electron from it to produce an ion there is nothing but a proton left and the system has no story to tell as regards light. It is for this reason that Dr. Maxwell

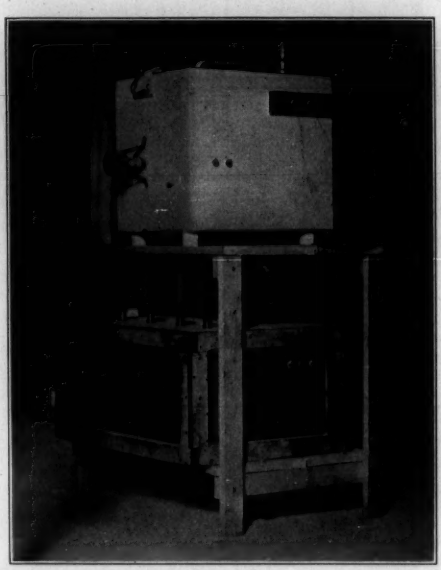
has decided upon the next simplest atom, helium, and when the data have been obtained for this gas, it should be possible to make very interesting comparisons between the experimental results and the predictions of atomic theory.

The Possible Influence of Cosmic Rays on Radioactivity.—Last year I stated that Dr. Maxwell was just about to carry out an experiment on the origin of radioactivity; this experiment has since been completed,[6] and I will give a short account of the procedure and results. The experiment was suggested by a proposal of M. Perrin to the effect that the disruption of atoms which we find in the case of radioactivity may be brought about by a penetrating radiation coming from outer space, a radiation which we now know to exist and which is probably familiar to you, under the name of cosmic radiation. This is not the first time that an endeavor has been made to check Perrin's theory, but the experiments of Dr. Maxwell are somewhat different from those performed formerly. In the first place he uses polonium as the radioactive material with which to make the test, and here the catastrophe suffered by the atom in the emission of an alpha particle, i.e., a positively charged atom of helium travelling with a velocity of about 12,000 miles per second, whereas in former experiments the main catastrophe suffered was the emission of a beta particle or a gamma ray. I must remind you that the radiation which comes from radioactive material possesses the power to render air conducting, and it is by measuring the conducting power of the air that the intensity of these radiations is measured. If the disruptive process should be decreased, then the intensity of the radiations and the conductivity imparted to the air would be decreased also. Dr. Maxwell has measured the activity of the radioactive specimen at the surface of the earth, and then again at the bottom of a coal mine 1150 ft. deep. It is calculated that the absorbing power of the earth above the specimen would in this case be the equivalent of about 400 ft. of lead, and this should cut down the cosmic radiation to an insignificant amount. Thus if the cosmic radiation were itself responsible for the occurrence of radioactivity, the specimen should show a very

[6] "Cosmic Radiation and Radioactive Disintegration," *Nature*, December 29, 1928: also, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 207, pp. 619–628, 1929.

marked decrease in its activity at the bottom of the coal mine. Fig. 9 is a picture of the actual apparatus used, and Fig. 10 is a diagram of it. A rod connected to a unifilar quartz fibre electroscope, carried a disc, and extended into a chamber in which ionization was produced by the radioactive specimen. The specimen itself was located at the point *a*.

FIG. 9.

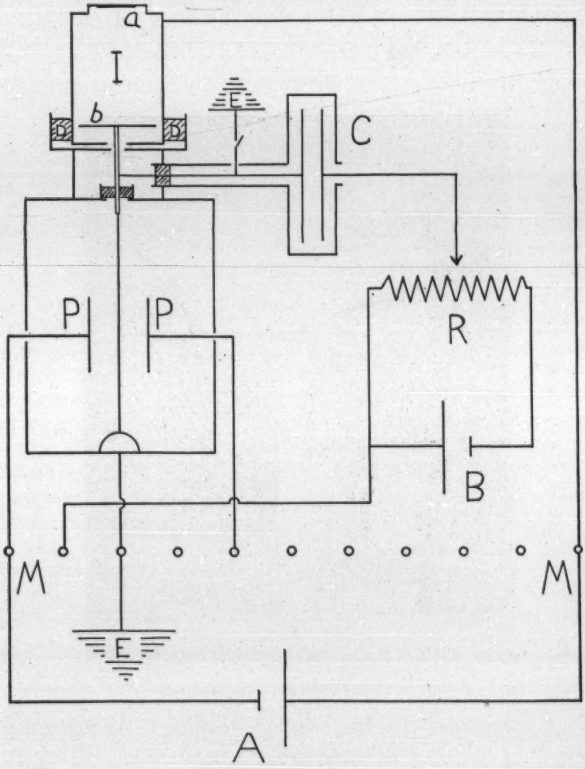


View of the apparatus which was taken into the mine.

It was mounted so that its position in relation to the ionization chamber could be made very definite, as of course, for a comparison of the conditions in two different locations to be of any value, it was necessary that the relation between the radioactive body and the air should be exactly the same in the two cases. I will not describe the detail of these measurements further than to say that rather exceptional precautions were

taken to eliminate the ordinary errors in measurements of this kind, and the result was to show that any effect of the cosmic

FIG. 10.



Experimental Arrangement.

radiation was such as to alter the radioactivity of this specimen by certainly less than one per cent.

I think that with our present knowledge of the quality

and properties of the cosmic radiation, it is possible to see that there is very little likelihood of explaining radioactivity as the result of the cosmic radiation. The energy of a cosmic ray is such as to enable it to produce about 5 million ions. If, in accordance with experimental determinations, we assume that the cosmic rays produce ions at the rate of about 1.4 ions per c.c. per sec. at sea level, then there must be on the average about 1.4/5,000,000, that is, about 2.6×10^{-7} primary cosmic rays absorbed per cubic cm. per sec. of air at atmospheric pressure. This amounts to an absorption of about 1.3×10^{-4} primary cosmic rays by a gram of absorbing material. Now an estimate of the amount of polonium on the plate in Dr. Maxwell's experiment shows that he must have used about 10^{-11} of a gram. It is therefore clear that we should only expect a cosmic ray to be absorbed by one of these atoms once in about 10^{15} seconds, that is once in 20 million years. Dr. Maxwell is a young man, but I fear that I, at any rate, should not be able to report to you the annihilation of a cosmic ray by one of the atoms on Dr. Maxwell's plate. Similar considerations apply to all experiments of this kind, which have been performed to test the possibility of the cosmic radiation as an origin of radioactivity. It is only within the last few years, since our knowledge of cosmic rays has become as definite as it is, that it has of course been possible to draw such a conclusion as this.

The Production of X-Rays by Protons.—One of the most fundamental problems in atomic physics centers around the production of X-rays. Ordinarily, X-rays are produced by the impact of high speed electrons on atoms, and the modes of their production divide themselves into two classes. The first mode is concerned with the so-called general X-radiation, in which an electron impinges on an atom and may lose part or all of its energy with the corresponding conversion of that energy into wave-lengths of radiation of an X-ray type. Then we have what is called the characteristic X-radiation, where the swiftly moving electron hurls an electron from its normal orbit in the atom into some outer orbit from which it falls back with the subsequent emission of X-radiation. The process here is of course exactly analogous to that which I have already referred to in connection with the emission of

light from the atom, the X-ray being a very short wave-length form of light.

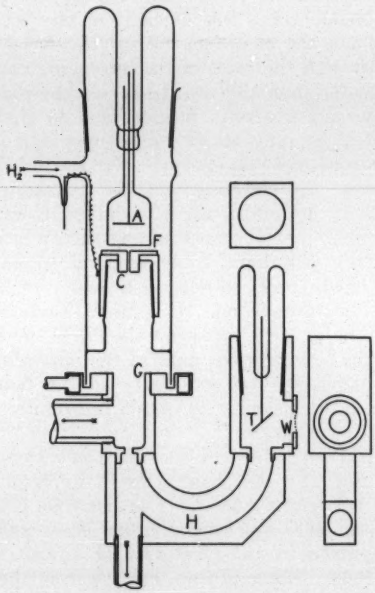
The question arises as to possibility of producing X-rays not by the impact of electrons, but by the impact of positively charged atoms such as protons. Any theory of the process of emission of X-rays would have something to say as to the manner in which the efficiency of X-ray production depends upon the mass of the charged particle used for bombarding the atom; and, in view of the great difference between the mass of the proton and the electron, information as to the relative efficiency of production of X-rays by these two agencies would form a very valuable control upon any theory of the process. Then, there are other laws which are fundamental in connection with our notions as to the nature of atomic processes. One of these tells us that in the case of the production of X-rays by electrons, the highest frequency of the general radiations emitted is such that Planck's constant h times this frequency is equal to the energy of the electron. It would be of very great interest to ascertain whether a similar law held in the case of the production of X-rays by protons. Unfortunately, all reasonable considerations as to the mechanism of production of the general X-radiation are such as to indicate the efficiency of that production to be very small compared with the corresponding efficiency for the production of X-rays by electrons. Indeed, it seemed until comparatively recently, that it would be hopeless to attempt to detect the general radiation from positive ions, and Dr. Barton concentrated his attention at first on the problem of determining the efficiency of production of the characteristic X-radiation; for here, while theory does not go so far as to speak with definiteness as to the efficiency of this radiation, it does not have such a drastic story to tell as to its smallness as is the case for the general radiation. As the method has developed, however, it now turns out that Dr. Barton is approaching a sensitivity in his apparatus where he hopes to detect the general radiation; but, in accordance with the general and well tried principle of the cussedness of all inanimate things, the characteristic radiation has apparently decided to compete even with the general radiation itself in smallness, so that it is possible that its detection will be

attended with difficulty as great as that associated with the detection of the general X-radiation itself. The experiments, as they have progressed so far, have succeeded in placing an upper limit to the efficiency of production of both kinds of these radiations. While the result, therefore, is negative, it does give us definite information with regard to the mechanism of the process. The net result so far has been to show that compared with electrons of the same energy, the protons are at least a 100,000 times less efficient in the production of X-rays than are the electrons. Thus the X-ray efficiency must diminish with the mass of the impinging corpuscles, to an extent greater than the first power of the mass. For if the efficiency were inversely proportional to the mass, the radiation would be only about 2,000 times less for protons than for electrons of equal energy. Dr. Barton hopes to be able to increase the sensitivity of his measurements by a factor of at least 40, and if the X-radiation from protons is still undetectable, it will mean that any theory to provide for their occurrence will have to correspond to an efficiency which is inversely proportional to a power of the masses greater than even the second. It is indeed probable that the efficiency of the general radiation should be inversely proportional to the square of the mass of the impinging particle, so that by increasing the sensitivity to the figure I have named, it should be possible to obtain information upon the general radiation itself.

The general procedure in Dr. Barton's experiments is indicated in Fig. 11. An electric arc in hydrogen is set up in the region between *A* and *F*. The electrode *C* is provided with a hole; and, as is well known, under these conditions the arc is accompanied by the projection of a beam of protons through the hole. These protons emerge from the hole with comparatively small velocity, and are accelerated by means of an electric field between *C* and *G*. It would be inconvenient to use the protons at the point *G*, because, in the first place, they are mixed up with hydrogen ions composed of two and three atoms of hydrogen in groups; and, in the second place, ordinary X-rays produced in this region of the apparatus by means of the electrons operating the discharge, ultra violet light, etc., would be operative to complicate the results

obtained. For these reasons, the protons are bent around into a circle by means of a magnetic field, and are brought to a convenient focus at a point on the target T. Here they have an opportunity to produce X-rays which are allowed to pass through the thin celluloid window W into the measuring chamber which in this position can be thoroughly well shielded

FIG. 11.



by lead from extraneous influences. The method used to detect the X-rays is that employing the so-called Geiger counter. This consists of a point enclosed within a small cylinder, a potential difference being maintained between the point and cylinder of such amount as to cause the insulation of the air to be just on the point of breaking down. If an X-ray enters this chamber there is a certain chance that it

will cause ionization within, and if it does so, the breakdown of the insulation is precipitated and a large current flows across the ionization chamber. It is obviously possible to arrange matters in such a way that this current is recorded by an electroscope in the form of a sudden kick of the fibre of that instrument. A resistance connecting the fibre of the electroscope to earth enables the instrument to discharge after experiencing this kick, and it is then ready for any other X-ray which may come along. Of course, only a fraction of the X-rays entering this chamber produce an effect, but it is possible to calibrate the instrument as regards its sensitivity by replacing the beam or protons by a beam of electrons of equal energy. If we assume that the X-rays produced by protons and electrons of the same energy have the same wave-length, then the calibration by means of electrons enables us to determine accurately the relative efficiency of electrons and protons for the production of these X-rays. This assumption as to the equality of the wave-length produced by equal energies of protons and electrons is not vital to the experiment; for, it is possible to calibrate the instrument with a whole range of electron energies, and to perform the experiment with positive rays over the whole possible range of energy, and so compare the efficiency corresponding to any proton energy with that corresponding to any other electron energy.

It may be of interest to remark that the sensitivity of the arrangement adopted is such that it will detect X-rays with an electron beam of only 10^{-14} ampere while ordinary X-rays are usually produced by a current of about 10^{12} times this. The proton current which it is possible to use so far has attained values as high as 10^{-9} of an ampere, that is, 100,000 times as great as the electron current which would produce measurable X-rays. One great advantage of this type of X-ray measurement is that it is quite independent of fortuitous disturbing conditions. In a counter of this kind, we always find that a number of fictitious kicks of the fibre take place, even when no X-rays are falling upon the apparatus, and the procedure is of course to take the difference between the numbers of these kicks per minute when the X-rays are off and on. As may readily be seen, if we should take the

kicks obtained for a minute with the X-rays, on and then for a minute with the X-rays off, then for another minute with them off, another with them on, and so forth, extending the observation over a very long time, the sum of the kicks obtained with the X-rays would differ from the sum of those obtained without them by an amount which was accurately representative of the effect of the X-rays themselves, independent of any assumption as to the constancy of the disturbing influences over a long period; and by extending the period of the observation even to the extent of days or weeks, the result would be increasingly reliable as regards their ultimate interpretation. It is very easy to change the conditions from that in which the X-rays are operative to that in which they are not. All that is necessary is to change slightly the magnetic field used to bend the original beam of protons so that the beam fails to fall exactly on the X-ray target. By this process everything is the same in the off and on measurement except for the one feature which we wish to investigate—the effect of the protons striking the target.

The Influence of an Alternating Electric Field on Light Transmitted through Water.—I now wish to turn to certain experiments performed by Dr. Bramley and having to do with the nature of light.[7] Modern physics has distinguished itself from the older physics by one harassing, but at the same time, alluring characteristic. In the old days, after we had devised some new theory to replace an old one, it usually followed that if a check written on the account of the more obvious predictions of the new theory was not honored by nature, a check written on the account of the old theory as regards its predictions would also not be honored. But in the physics of the last ten years we have continually come across situations of the following kind. We have our old theory A and our new theory B. We have been driven inevitably from A to B by certain facts. Then, strong in the confidence of B, we have tried some experiment which B predicted, and found that lo and behold, it went according to A, and vice versa.

[7] "Modulation of Light Waves," by A. Bramley, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 207, March 1929.

When light passes through a medium such as water, the molecules of water are acted upon by the light with the result that they absorb some of it and re-emit it with the same frequency. Now, when the water is subjected to an alternating electromagnetic field as well as to the field of the light wave, if the process of light emission went on according to what we call the classical theory of optics, the emitted light would consist of a part having a frequency equal to that of the original light beam, a part having a frequency equal to the sum of the frequencies of the light and of the electromagnetic field, and a part having a frequency equal to the difference of these frequencies. Now Dr. Bramley has performed this experiment using electrical oscillations corresponding to a wave-length of about a meter. Instead of

FIG. 12.

obtaining what the classical theory would predict, Dr. Bramley obtained merely a shift of the spectrum lines corresponding to the original light, and the shift was towards the longer wave-length. The shift is very small in amount, only about the one-600th of a hundred millionth of a centimeter, or about two hundred thousandths of the original wave-length. Moreover, if we should use a source of light comprising a number of different lines, only certain of these lines show a shift. Fig. 12, for example, is a spectrum of one of the sources of light used. It is an iron spectrum. The lines with arrows show shifts, while those without arrows show no effect. The results are thus contrary to the simple classical theory and what has the quantum theory to say about the matter?

In one possibility we picture the electronic orbit in our water molecule as disturbed by the field after the manner of what we know as the Stark effect. If we follow the lines of ordinary absorption theory in such a situation, we find that

the light pays attention only to those orbits which have not been altered, and the net result of these considerations would be to predict that the frequency of the light emitted was the same as that for the light absorbed. If, however, we do not tie ourselves down too rigidly to this picture, and permit the energy of the original light to split itself into two parts, one of which is concerned in producing in the atom a transition corresponding to a frequency less than the frequency ν of the original light, by an amount p, the remainder going to produce somewhere in the atom a transition corresponding to the frequency p, the net result would be that the atom would re-emit frequencies of amount $\nu - p$ and p. The frequency p would in general be too small to observe. On such a view it is of course not immediately obvious as to why certain spectrum lines should participate in the effect while others do not.

Another possibility which has occurred to Dr. Bramley utilizes the principle of the Compton effect. I will remind you that if X-radiation falls upon an electron, and for simplicity let us say a free electron, the electron receives energy and momentum from the light wave, and the latter suffers a change in wave-length towards the long wave-length side. Under ordinary conditions, the phenomena does not take place in the case of visible light because all of the electrons are too firmly bound, and the theory of the Compton effect tells us that under these conditions the change of wave-length cannot occur. If we assume that the effect of the electromagnetic radiation is to loosen the binding between the electrons and the atom, we may regard the displacement in the spectrum as simply evidence of an action of the Compton effect. In favor of this view we observe that the actual shift is of the right order of magnitude as calculated from the Compton effect. It may be observed that since Dr. Bramley suggested this possible explanation, a somewhat similar invocation of the Compton effect has been made to explain the shift of the wave-length of certain stellar spectrum lines as the result of the action of the free electrons in hot stars in modifying the light emitted by those stars. In support of this view, moreover, we have evidence of the existence of loosely bound electrons from another standpoint; and here I must

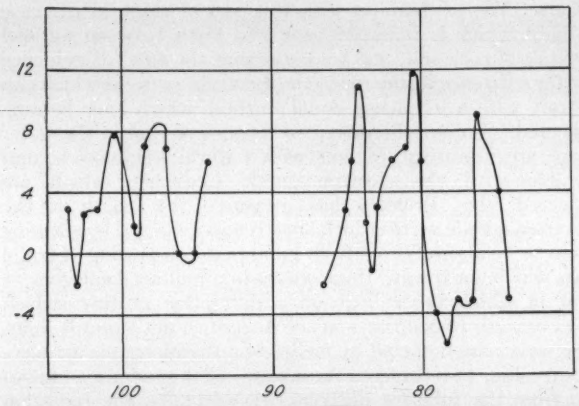
make a digression to speak of another investigation which Dr. Bramley has carried out.[8] It concerns the existence of a situation in water which results in the water responding to certain electromagnetic vibrations, i.e., certain frequencies more than to others.

If an electromagnetic wave composed of a variety of wave-lengths is allowed to pass down a cylinder surrounded by water, reflection of the waves occur back and forth between the surfaces of the water and the reflection is much stronger for certain frequencies of electromagnetic waves, than for others. We are familiar with this sort of thing in the case of light which is reflected back and forth between parallel crystals of rock salt, and we know that the effect is evidence for the existence in the rock salt of certain systems which can vibrate with a frequency equal to those which have become reflected. We are therefore, led to suppose that in the water there are vibratory systems with natural frequencies comparable with the electromagnetic frequency which are reflected. Dr. Bramley has measured the length of the electromagnetic waves which are strongly reflected by allowing them to be also reflected from an improvised grating of metal bars which act toward these waves in a manner analogous to that in which the rulings on a diffraction grating (which however, are 10,000 times nearer together) act towards light. The waves are detected by means of a thermocouple arrangement. Fig. 13 represents the amount of the radiation emerging from the tube for different wave-lengths, the radiation going in being more or less evenly distributed in the wave-length. We observe that the intensity curve consists of bands whose frequency difference is constant. This is exactly analogous to the effect obtained in the corresponding optical experiment. There is an oscillation of a fundamental frequency, a radiation of double this frequency, triple the frequency, and so on; and, all of these are reflected. The frequency of the fundamental oscillation is equal to the difference of the frequency between two adjacent peaks, and the actual frequency is about three times 10^{10} vibrations per second, a frequency a hundred thousand times smaller than

[8] Kerr Effect in Water Due to High Frequency Waves, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 206, pp. 151–157, 1928.

that of light vibration, and therefore corresponding to some sort of an oscillator different entirely from those we ordinarily associate with atoms. Now oscillators of this kind, if set in motion and left to themselves, die down owing to the radiation of their energy. If we measure their frequency, and the rate at which they die down, then, on the assumption that the emitted energy is emitted according to classical electromagnetic theory, it is possible to calculate the mass of the part

FIG. 13.



The ordinates represent the relative amounts of the absorbed energy, the abscissa the reciprocal of the wave-length $\times 10^{-4}$. The two curves correspond to apparatus of different dimensions. The exact procedure for obtaining these particular curves was different from that outlined in the paper, but it was hardly necessary to describe the differences in detail.

which oscillates, and also the magnitude of the forces which control it in its oscillation. Now, Dr. Bramley has been able to determine the rate at which these oscillations lose their energy. The determination depends upon considerations which invoke the assumption of a picture of what is taking place, but the fact supports the picture, and the picture is as follows. It is supposed that the electrons associated with the water are not free until the electromagnetic oscillations come into play. They then come into existence under some small restoring force which determines for them a period of

oscillation. If the frequency of the electromagnetic radiation coincides with the natural period, the number of the electrons freed is large. Now, when the electromagnetic radiation is removed, the oscillation continues in the water, dying down at a rate determined by the mass of the system which is oscillating. As a result, the effect of the water on the light persists for a certain time after the removal of the radiation. By measuring the rate at which this peculiar condition of the water disappears after removal of the radiation, we can calculate the mass of the oscillating part. It turns out that the mass is equal to the electronic mass, so that the interpretation of the primary optical effect produced by the electromagnetic radiation in the water is consistent with the assumption that it is due to the presence of loosely bound electrons; and, the existence of such loosely bound electrons is in harmony with the kind of characteristic frequencies found for the water, and with the time of persistence of the optical effect after the removal of the electromagnetic radiation.

The one difficulty which faces the Compton effect as an explanation for the shift of the lines obtained in Dr. Bramley's experiment, is the fact that it may occur for one line and fail for another which is quite near to it in wave-length. It would be very arbitrary to assume that in the water there were certain conditions which favored certain of the spectrum lines in relation to others having practically the same frequency, unless two lines having practically the same frequency may differ in other ways. We have, however, to remember that different lines are produced by transitions between different energy levels in the atom. It is not impossible that two lines of the same frequency may nevertheless have entirely different lengths of wave trains depending upon the nature of their origin in the atom, and the length of the wave train may play an important part in the theory of the phenomenon.

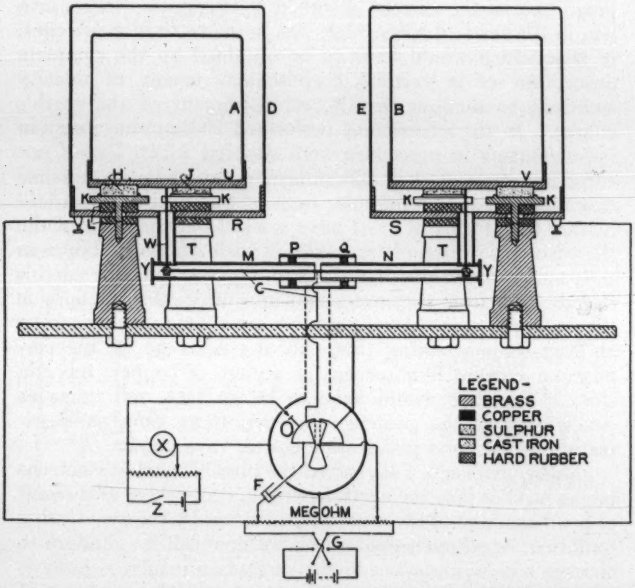
I may add that there is an interesting feature attending the existence of these characteristic frequencies in water. There is at present much interest in the effect of electromagnetic radiation on animal tissues, particularly in relation to the cure of cancer. Dr. McDonald, who I am happy to say is with us this evening, has been particularly interested in

furthering this line of investigation. Now I believe it is found that the main primary effect of the electromagnetic vibrations on the animals is to raise the temperature, and that certain frequencies are much more effective in this matter than are others. We now see readily how this can be the case. If the electromagnetic frequencies happen to coincide with fundamental frequencies inherent in the structure of the tissue, we may expect that energy will be absorbed from the electromagnetic radiation very much more copiously for these frequencies than for others, with the resulting enhancement of the heating effect.

A Search for Corpuscular Radiations of Cosmic Origin.—I now turn to another investigation having to do with the very fundamental problem of the origin of the earth's charge, an investigation which was carried out by Mr. Longacre and myself last summer. It represents the repetition under more refined conditions of an experiment which I carried out under the auspices of the Bartol Research Foundation about four years ago in Norway. I must remind you that the earth is not a neutral body. Its surface is coated with a charge of negative electricity of such amount as to cause a difference of electrical potential between the surface of the earth and a point 1 meter above it, about one and a half times as great as that between the terminals of our lighting circuits. Owing to the fact that the atmosphere is a conductor of electricity, ninety per cent. of this charge would disappear in ten minutes if there were no means of replenishing it. One class of theories which has been proposed to account for the replenishment of this loss invokes the agency of corpuscules which are shot into the earth from the atmosphere or from regions outside it, against the forces of the electric field. If such corpuscles exist, we might expect to be able to detect them by insulating a massive body and allowing it to charge up as a result of absorption of those corpuscles which try to pass through it, and get absorbed. I took the opportunity to try this experiment four years ago when I was in Norway, since that locality is favorable to the existence of the Northern Lights, so that it seemed that there might be a greater chance of corpuscular precipitation in those regions than elsewhere. Fig. 14 represents the apparatus which I used, and it is essen-

tially the same as that which was used last summer when Mr. Longacre and I were in Ithaca. *A* and *B* are two hollow vessels, which are shielded by the other metal vessels, *D* and *E*. The two hollow vessels are connected together and to the two insulated quadrants of a quadrant electrometer.

FIG. 14.



The outer vessels are connected to equal and opposite potentials, so that any currents which come to the vessels as the result of conductivity of the air between the inner and outer vessels, tend to annul each other. The plan is first to observe any apparent rate of deflection of the electrometer with the two central vessels empty. The left hand central vessel is then filled with a solid cylinder of copper, and another set of readings is taken. Everything is the same as when the vessels

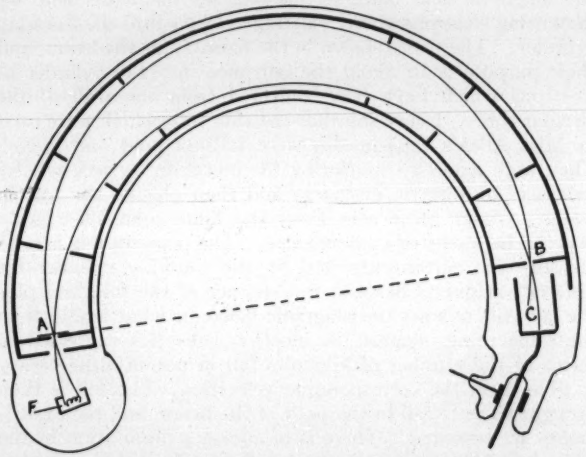
are empty except for the addition of any corpuscular radiation which may be absorbed by the copper. Of course, the usual precautions were taken, and the copper was first placed in one vessel, then in the other vessel, and then back in the first vessel, and so on; and, the observations were combined in such a way as to eliminate all of the obvious sources of error. The Norway experiment showed that the absolute magnitude of the current absorbed by a copper cylinder 20.6 cm. in dia. and 19.3 cm. high was no more than 5 per cent. of that which would have to be obtained by the complete absorption of a vertical corpuscular current of density sufficient to account for the replenishment of the earth's charge. In the experiment performed last summer, certain improvements in procedure were adopted which I need not enter into now and it will suffice to say that the possible magnitude of the corpuscular current was pushed down still further by a factor of 8. I have worked out the story of the theory of absorption of corpuscles in such a mass of copper as this, and it turns out if we are to suppose that the earth's charge arises from corpuscles shot into the earth from outside the atmosphere in this manner, we must suppose them to be at least so penetrating that only 0.5 per cent. of the corpuscular current is absorbed by a piece of copper, 100 cm. thick. The rays would have to be, in fact 700 times as penetrating as the gamma rays, and three times as penetrating as the most penetrating cosmic rays known.

Many years ago, I suggested the possibility that electrons might be shot into the earth from the atmosphere as a result of bombardment of the atmospheric atoms by the penetrating radiation, or cosmic radiation, as we now call it. Failure to observe a charging effect in the case of an insulated body is not necessarily conclusive evidence against the existence of a corpuscular current having its origin in this manner; for, the cosmic radiation will fire electrons out of the under portions of the body as well, into the upper portions, so that the net charging will depend upon the absorption of the cosmic rays themselves in the substance of the insulated body. When the foregoing experiments are considered in this light, from a theoretical standpoint, they show that to account for a corpuscular current sufficient to maintain the earth's

charge, it would be necessary to postulate a very intense cosmic radiation, and one of penetrating power enormously large compared with the penetrating power of any such radiation as has been observed.

The Loss of Energy by Electrons in Passing through Thin Foils.—I will now refer to an investigation being carried on by (Miss) Dr. Allen, concerning the passage of electrons through thin metallic foils. We know that when electrons of sufficient speed strike a metal, they hurl some of the electrons

FIG. 15.



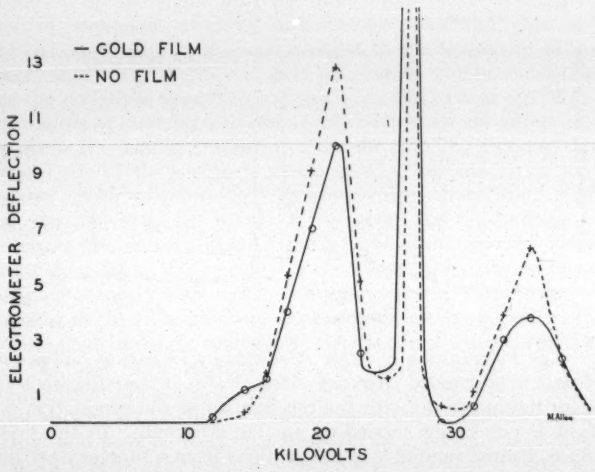
from the inner orbits of the atoms, and these electrons in falling back produce the so-called characteristic X-rays. On allowing a homogeneous stream of electrons to fall upon such a foil therefore, we might expect, on examining the electrons which came through, to find that some of them came through with the original velocity, and that others showed evidence of having lost different amounts of velocity to an extent determined by the energy necessary to produce the characteristic X-radiation. Theory indicates that the number of electrons which would suffer this catastrophe in a thin foil

would be very small, so that a very sensitive arrangement is necessary in order to detect them. The apparatus used by Miss Allen is indicated in Fig. 15. The beam of electrons originates in a hot filament, and is accelerated by an electric field between F and the slit below A. It then passes through the slit at A, is bent by a magnetic field into a circle and brought to a focus in the well known manner at the opposite end of a diameter, where it enters a little metallic Faraday cylinder C which is connected to an electrometer. The radius into which the electrons are bent depends of course upon the magnetic field; and, by varying the magnetic field, we may bring electrons of any existing velocity into the Faraday cylinder. The vanes shown in the figure limit the beam, and their purpose is to avoid the entrance into the cylinder of electrons which have been reflected from the wall of the circular tube. I may say that the thin foils which were used in Miss Allen's experiments were foils of gold and nickel. They were made by sputtering the metal on to rock salt by means of an electric discharge and then placing the salt in water. Under these conditions the films come off readily and can be mounted conveniently. The procedure is first to measure the current received by the Faraday cylinder for different magnetic fields in the absence of the foil, and plot the currents against the magnetic fields, or what amounts to the same thing, against the electron velocities expressed in terms of the number of kilovolts fall in potential necessary to give them the corresponding velocities. The foil is then brought so as to fall in the path of the beam, and the experiments are repeated. There is of course a diminution in the intensity of the primary beam, as the result of the scattering which the electrons have suffered in the foil. The curves with and without the foil are shown full and dotted, respectively, in Fig. 16, for the case (zero scattering) in which the electrons observed travel in the direction of the original beam. They are reduced to such relative scales that the area, which would correspond roughly to the total number of electrons transmitted, is the same for each. This adjustment of the scales of course, neglects the scattered electrons, and is only approximate. I may say that the side humps which are obtained even in the absence of the foil have been shown

to be due to the reflection of electrons which has occurred from the edges of the vanes. Their relative importance may be gauged from the fact that if the dotted curve were completed on the scale of Fig. 16, its main peak would be about 350 cms. high.

Thus, as we might expect, the electrons which pass through the foil unscattered show no marked change in velocity. On the other hand, Fig. 17 shows the corresponding curve for a

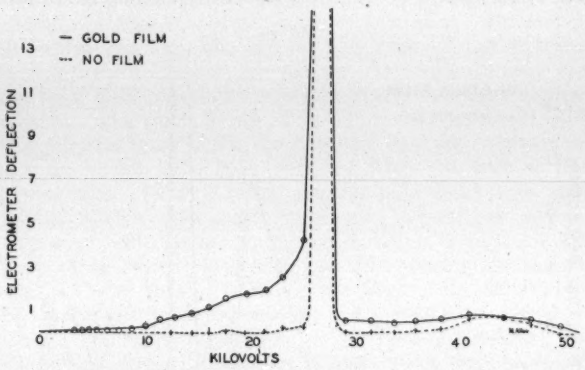
FIG. 16.



case where the original electron beam is inclined at an angle of 8° to the former direction. The limitation of angle by the vanes is sufficiently small to permit the original beam still to make itself evident on the graph, but there is now a marked difference between the curve with and without the foil; and, the changes of velocity of the electrons from the maximum value appropriate to the central beam are, as we should expect, in the direction of a reduction of velocity. As the angle made by the original beam with its symmetrical position, is still further increased, the main beam disappears from the figure, on account of its absorption by the vane; but,

there remains a portion of the curve which corresponds to the scattered electrons which have lost velocity in passing through the film. By an interpretation of such curves as these, it should be possible to arrive at interesting conclusions concerning the mechanism of loss of velocity by these electrons in passing through the film.

FIG. 17.



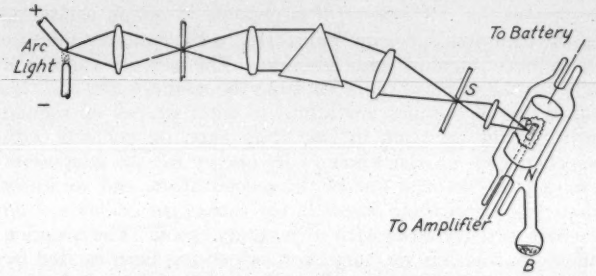
The Polarization of Light Produced by Impact of Cadmium Atoms with Excited Mercury Atoms.—An interesting experiment having to do with the mechanism of the production of light is one being carried on by Dr. Mitchell. In the first place, I must remind you that if light from a mercury arc be allowed to fall upon mercury vapor, the vapor itself will emit light and this light is known as resonance radiation. If the original light is plane polarized, that is to say, if its vibration takes place parallel to a fixed line, then we find that the resonance radiation is also plane polarized with vibrations parallel to that line. This fact has always seemed to some extent peculiar, because, at any rate, in terms of our notions of a few years ago, we have thought of the original radiation as changing the orbit of some electron in the atom upon which it falls, to an orbit of greater energy, so that the electron in falling back to its customary orbit emits the resonance

radiation. Some considerable time may elapse before this return to the original orbit takes place, and the problem has been as to how the atom remembers the direction of the polarization of the exciting light so as to hand it on to the light which it emits. Now the experiment which Dr. Mitchell is performing is one which calls for an even more drastic test, as it were, of this "memory of the atom." He uses for the experiment, a mixture of mercury vapor and cadmium vapor. The spectrum lines of cadmium vapor can not be excited directly by the radiation from mercury, because in order to excite resonance radiation, it is necessary that the frequency of the on-coming light shall be equal to the frequency of the resonance line. However, it is possible to obtain excitation of the cadmium spectrum indirectly, in the case of a mixture of vapors of mercury and cadmium. The mercury vapor first absorbs the primary radiation from the mercury arc, and this raises one of the mercury atoms to what we call an excited state. Now an atom in this state may, on collision with another, give up the whole of its energy for the purpose of exciting the spectral line of the second atom, and we know that this sort of thing occurs in the case of the collision of an excited mercury atom with a cadmium atom. The question arising is this: the mercury atom which has been excited by plane polarized light remembers the nature of the polarization of the light long enough to endow the radiation which it emits with that polarization. Will it remember this condition during the act of communicating its energy to the cadmium atom and pass on to it that property of polarization, so that the cadmium light itself will become polarized in a direction parallel to that of the original light in the mercury arc?

Experiments on the Photoelectric Effect in Thin Films of Potassium and Sodium.—I now turn to certain experiments carried out by Dr. Nottingham, on the photoelectric effect. As you will recall, the photoelectric effect is the emission of electrons from matter as the result of the impact of light. Our knowledge of it so far has been characterized by certain features of which the following are the most prominent. In the first place, for any substance, there is a frequency of light below which no photoelectric effect occurs. Then, the number of electrons emitted per second from the surface is

proportional to the intensity of the light. Again, if we plot against the frequency, the maximum energy of the electrons emitted by the light, we obtain a straight line, and the slope of that straight line is equal to a quantity h, which is known to all physicists as one of the most fundamental constants in Nature. Now Dr. Nottingham has carried out tests of these facts for the case of potassium and sodium in the form of very thin films, and he has found very marked departures from the laws, departures which are very significant in their relation to the mechanism of the whole procedure. Fig. 18 shows the

FIG. 18.

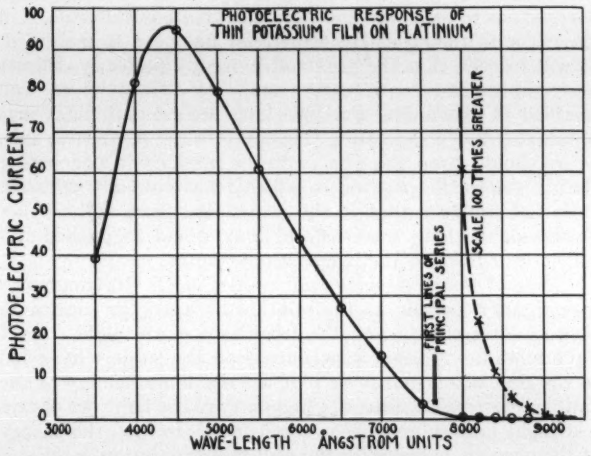


photoelectric cell used by Dr. Nottingham. The light from a carbon arc passes through a monochromatic illuminator, which splits it up into a spectrum and enables us to illuminate the photoelectric cell with light of any wave-length we choose. The light passes through the slit S and falls upon the potassium surface P. The sensitive surface is surrounded by a cylinder N of nickel, which serves to shield it from electrical disturbances. An electrical potential difference is set up between the nickel cylinder and the sensitive surface, and the surface itself is connected to an electrical measuring device, the details of which I will not now describe. It will suffice to say that this device will measure electric currents of the order of magnitude of 10^{-14} of an ampere, and so measures the currents associated with the electron emission from the sensitive surface. It is possible to coat the surface with potassium by evaporating potassium from the side bulb B, and, if

necessary, to remove that potassium from the cylindrical surface by heating a filament placed inside it.

The maximum velocity of electrons emitted by the light from the sensitive surface was obtained in the usual way by finding the potential difference between the cylinder and the surface necessary to stop all electrons leaving the surface. One of the points of interest in Dr. Nottingham's experiment concerns the frequency, or wave-length, at which the photo-

FIG. 19.



electric effect starts in, the long wave-length limit, as it is called. I will call your attention to Fig. 19. Plotted vertically, we have the photoelectric current, and horizontally the wave-length. You will see on referring to the left hand curve, that towards the long wave-lengths, the curve falls down to very low values. We might well suppose that if we should produce this curve down to the horizontal axis, the wave-length at which it would intersect the axis would represent the long wave-length limit, and indeed the value obtained in this way, and indicated by the double arrows, agrees with that of former observers. You may ask, what

about the tail to the right. It has been customary to ignore the tail on the basis that the observations are very small, and that the tail represents something irrelevant. However, this tail is a more powerful part of the animal than might be supposed at first sight; and, if we magnify the vertical scale, we obtain an entirely different story. Under ordinary conditions the sensitivity of the apparatus would not be great enough to warrant increasing the scale in this way, but the sensitivity of Dr. Nottingham's apparatus was about a thousand times greater than that of recent observers, and was such as to fully warrant such an increase in the scale. In the curve to the right, the sensitivity has been so increased. It will be seen that the points still occupy perfectly definite positions on a smooth curve; and, we should be as well justified in concluding that the long wave-length limit was obtainable by extrapolating this curve to the horizontal axis, as we should from the first curve be justified in concluding that it was in the position to which I have already referred. It is not unlikely that if the sensitivity were still further increased, the long wave-length limit would be pushed still further out towards the longer wave-lengths.

Some of the most significant results of Dr. Nottingham's investigation pertain to the relation between the maximum photoelectric energy and the frequency of the light. As I have remarked, former experiments on the subject have led to the conclusion that if we plot the maximum energy of the emitted electrons against the frequency of the light, we obtain a straight line whose slope is equal to h. In fact, the energy of the electron is given by the well known relation

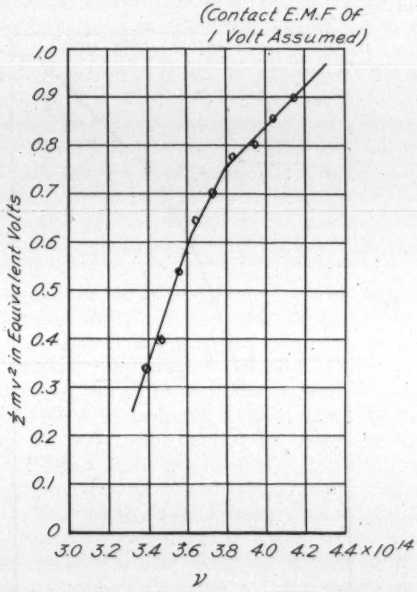
$$\tfrac{1}{2}mv^2 = h\nu - w.$$

We have been accustomed to interpret this by saying a quantum of light of frequency ν possesses an energy equal to $h\nu$, and falling upon the electron, imparts to it an energy $\tfrac{1}{2}mv^2$ which is equal to $h\nu$ less w, the amount of energy necessary for the electrons to escape from the atom and from the metal; for of course the metal surface exerts forces which oppose the exit of the electrons. Now, the results obtained by Dr. Nottingham are of the following character for very

thin films, that is films so thin that there is probably less than one molecular layer.

When Dr. Nottingham plots the energy of the ejected electrons against the frequency, he finds that the curve starts off as a straight line with a slope equal to $3h$, instead of

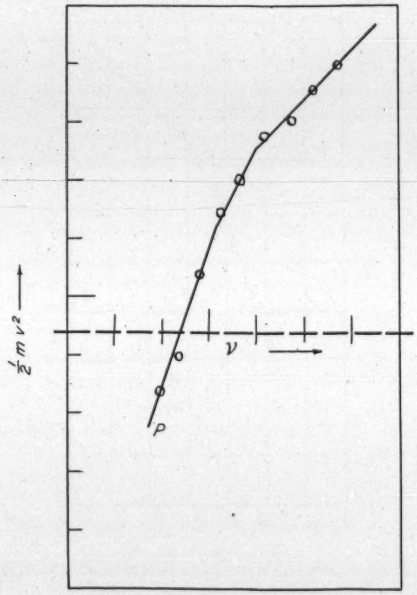
FIG. 20.



h, as former experiments would have suggested. Then, after a certain frequency is obtained, the slope of this curve becomes reduced to $2h$, and later on to h. We must not think that these results are drastically inconsistent with former experiments, the fact is that the very nature of former experiments was such that they could not possibly have brought out these particular points. I must say that in the first place, the apparent potential differences necessary to stop all of the electrons do not represent the actual potential differences

because of the existence of a certain contact difference of potential between the sensitive surface and the surrounding cylinder. The effect of this contact difference of potential, if it is unknown, is to produce an uncertainty in the value of the energy corresponding to the horizontal base line in Fig. 20

FIG. 21.



and which in that particular figure is arbitrarily represented as zero. We must admit the possibility of the curve actually going below this region and until we know what the contact difference of potential is, we must leave out the horizontal zero axis, as is done in Fig. 21, for example, where the dotted horizontal line is simply given to indicate the scale of frequency, and carries no significance in relation to the origin for

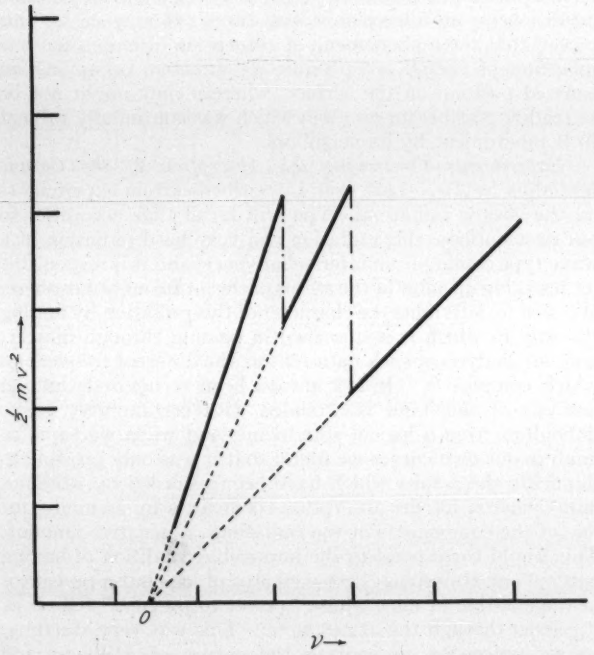
energy. Now, while I do not have time to enter into detail as to the experiment, I can say this, that the farther we go down Fig. 21 from right to left, the less the magnitude of the quantities which we have to measure in order to determine the points on the curve. In former experiments on thin films, the quantities to be measured had gotten so small that they were immeasurable, before one had gone sufficiently far down on this curve to reach the portion where the slope was anything other than h. Now, the sensitivity in Dr. Nottingham's experiment is about a thousand times that of former investigators, with the result that he was able to obtain a much wider range of the graph. As a matter of fact, even in his experiment we have no right to believe that the curve ends with the line of slope $3h$. It is quite possible that if the sensitivity were still higher it would continue further down with slopes $4h$, $5h$, $6h$ and so on, and indeed there is evidence of slopes as high as $4h$. What then is the significance of these slopes?

Dr. Nottingham has been able to form an explanation of these phenomena which, in its broad outlines, is as follows. Let us suppose that in the neighborhood of these frequencies the atom possesses the power to store up light quanta, and to emit the stored energy in the form of electron energy, from time to time. Let us suppose, for example, that when frequency such as that corresponding to the point P, Fig. 21, falls upon the atom, some mechanism in the atom is capable of absorbing three quanta before explosion, some of absorbing two quanta and some of absorbing one quantum before explosion. Since, in this portion of the curve we are confining ourselves only to the electrons of maximum velocity, it is natural to suppose that the velocity which we actually measure is that corresponding to the electrons which have been ejected with three quanta. Those ejected with two quanta of energy and one, are present, but they are not measured. Let us suppose now that as we raise the frequency we finally reach a frequency for which the probability of absorption of three quanta of energy diminishes very perceptibly. This consequence may be inherent in the frequency itself, or it may mean that the atom mechanism responsible for the absorption of the three quanta falls out of resonance

in some way with frequencies by the time this state is reached. We have, now, to confine ourselves to a case where the fastest electrons are those which have absorbed two quanta. Consequently, the slope of the curve will become $2h$. In a similar way, we may suppose that as the frequency is still further raised we reach a stage at which the slope becomes simply h. If this kind of mechanism is true, then we should expect that if we should measure the number of electrons which were emitted with a velocity equal to or less than the maximum velocity by an amount, let us say v, then corresponding to the frequencies which gave a slope $3h$ in Fig. 21, we should find the number to vary proportionally to the cube of the intensity of the light, because, the probability of absorbing one quantum of light per second would be proportional to the intensity of light, the probability that a second quantum would be absorbed by an atom which had already absorbed one quantum would be proportional to the square of the intensity of the light, and so on. Suppose now that, corresponding to the frequencies which gave a slope $3h$ in Fig. 21, we take a wider range of v from the maximum; we should expect to include in it some of those electrons which had been ejected by two quanta of light, and the number of these would be proportional to the square of the intensity. The situation we should have is as follows: if, for the frequencies corresponding to $3h$ and for a range of velocity from the maximum equal to a small amount v, we plot a curve showing the relation between the current and the intensity, we should obtain a curve in which the current was very approximately proportional to the cube of the intensity. If we should now extend the range of v, so as to delve down into those electronic regions which were partly composed of two quanta electrons, we should obtain a curve which showed itself proportional neither to the cube of the intensity, nor to the square, but to a mixture of the two. If we delve down still further, the first power of the intensity will also make its appearance. As we delve down further and further by increasing v, the first and second powers become more important in relation to the third. Now this is just the sort of thing that Dr. Nottingham obtains, and you will observe that these considerations, having to do with the magnitude of the photoelectric current, confirm the other

considerations having to do with the relation between the maximum velocity of the electrons and the frequency of the light. Returning for a moment to Fig. 21, I may say that there are some rather subtle points concerned with the fact that the different sections of the curve join up. A possibility,

FIG. 22.



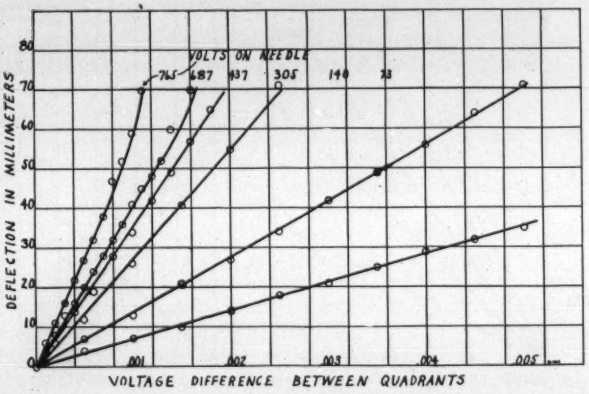
and a rather natural one consistent with what I have so far said, would be one in which the curve was divided up into sections, all directed towards a common point O, after the manner of Fig. 22. The story in this connection is, however, rather involved, and is too long for presentation at this time. In any case, the theoretical interpretation of Dr. Notting-

ham's results must be regarded as tentative at the present stage. In conclusion, it may be remarked that the situation of an atom on a surface is rather a peculiar one, when the number of atoms on the surface is so small that each one is far from its neighbors. Even in a gas the atoms collide frequently; whereas it is not impossible that an atom isolated on a surface in the way I have cited, may remain in an unstable condition for an appreciably long time. It may be for this reason that these phenomena of absorption of more than one quantum of energy are possible for an atom occupying an isolated position on the surface, whereas they might not be so readily possible for an atom which was continually subject to bombardment by its neighbors.

Experiments Concerning the Absorption of the Cosmic Radiation by Air.—Last year I described certain experiments on the cosmic radiation. You will recall that according to our past notions, this radiation is a very hard radiation of a wave type coming from interstellar space, and it is responsible for breaking up a few of the atoms of the air in our atmosphere. We seek to determine the character of this radiation by finding the way in which it is absorbed in passing through matter; and, an analysis of such data tells us the different frequencies which compose it. It has always been recognized that an analysis of this kind is attended with certain very grave difficulties from a logical standpoint, and when we came to analyze our own curves we found that it was only possible to duplicate the results which have been recorded by Millikan and Cameron for the absorption coefficients by assuming for one of the components of the radiations, a negative amount. This would correspond to the impossible condition of having entered our atmosphere, not a creator of ions but a preventor of the creation of ions, whose "power to prevent" fell off as it passed through the atmosphere. This was very startling, so we proceeded to analyze the curves of Millikan and Cameron for the same region of absorption, and found that the story was the same there for certain ranges of absorption. The story is rather a long one, and I have no time to discuss it in detail, or to do further than remark that the results of our analysis are such as to indicate that the greatest caution must be preserved in drawing conclusions as to the nature of these rays from experiments having to do with their absorption.

Instruments and Experimental Devices.—A number of experimental devices have been developed in the laboratory for various purposes in connection with the investigations which I have described. I can, however, do little more than mention two typical ones. In connection with the investigation on the photoelectric effect, to which I have already referred, it was necessary for Dr. Nottingham to develop a scheme for measuring small photoelectric currents, and he has devised a radio amplifying set which can be used in connection with a galvanometer so as to record currents of the

FIG. 23.

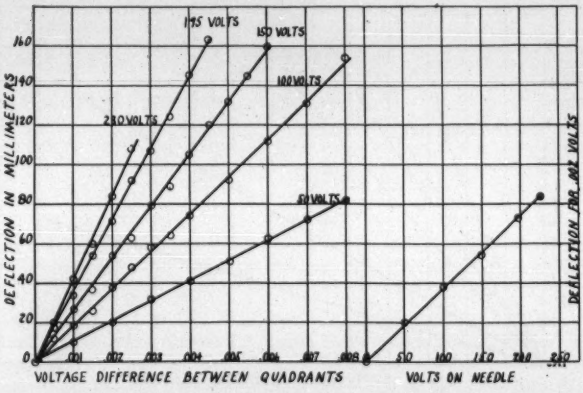


order of magnitude of 10^{-14} ampere, and measure these currents by the ultimate use of an ordinary galvanometer of the relatively short period of 10 seconds.

Then I have been interested in improving the behaviour of the ordinary quadrant electrometer. Those who are familiar with this instrument, will know that the simple theory of the instrument indicates that the higher the potential applied to the needle, the higher the voltage sensitivity, but in general, it is impracticable to apply a potential of more than about 100 volts, without reaching a condition of instability. It turns out from the mathematical theory of the instrument, that the causes which are responsible for the

instrument's instability depend very largely upon absence of planeness of the quadrants, with the resulting impossibility of making the whole of the quadrants perfectly horizontal. By careful attention to such matters it has been possible to produce an instrument in which a potential of 750 volts can be applied to the needle, and a sensitivity of 60,000 divisions per volt obtained with practically complete linearity over the whole range of the scale. Moreover, the ease of adjustment of the instrument at this sensitivity is about equal to that of the ordinary Dolezalek electrometer at a sensitivity of about

FIG. 24.



1000 divisions per volt. Fig. 23 represents a series of curves for different potentials applied to the needle, and Fig. 24, represents another series, together with a curve (the one to the right) showing the linearity between needle potential and sensitivity. It may be of interest to remark that in order to obtain stability with the potentials of the order of 750 volts on the needle, it is necessary that the quadrants shall approximate planeness to the order of a wave-length of light. I am hoping that we may be able to make still further improvement by making the four quadrants of the instrument out of a single plate of optically worked quartz. As those familiar with the quadrant electrometer well know, however, voltage

sensitivity is not all that is required of this instrument; for in the case of a very high voltage sensitivity, there is a sort of pseudo capacity which is brought about by the inductive action of the needle as it moves. In order to compensate this effect, I have recently devised an arrangement by which the motion of a spot of light from the electrometer mirror operates a photoelectric cell in such a manner as to feed into the quadrant of the electrometer a compensating charge to allow for this inductive action of the needle. I am hoping that by this means we may be able to compete in quantity measuring sensitivity with the voltage sensitivity already obtained.

THEORETICAL INVESTIGATIONS.

And then we have been interested in a number of theoretical problems. These for the most part, are of a highly mathematical nature, and it is only possible to touch upon them briefly here.

The Scattering of Electrons by Atoms.—The new wave mechanics, as it is called, the new formulation of the laws which tell the way in which things go on in the kingdom of the atom, has raised many new problems. When a beam of electrons is shot through a thin piece of matter, the beam suffers what is known as scattering, and we believe that if the scattering medium is sufficiently thin, the problem of this scattering can be studied by considering the scattering of a beam of electrons by a single atom. This problem has always been one of fundamental interest since, to use for a moment the more familiar language of theories of days gone by, the scattering is determined by the nature of the forces which the atom exerts in its immediate vicinity. In the new mechanics, we think of the scattering not in terms of forces exerted by the atom, but in terms of a guiding action of the electron by waves whose courses are twisted in the vicinity of the atom in a manner somewhat analogous to that in which light waves are twisted in passing by a point of strain in a piece of glass. It is possible to work out the scattering effect produced by an atom, provided that we make an assumption as regards the distribution of electrons within it. The problem was first attacked by assuming that the atom could be treated simply as a point charge. The next

step was to represent the atom as a positive charge surrounded by a shell of negative electricity which was roughly the equivalent of the electrons which surround the nucleus. This again was only an approximation. Within the last year or two, our ideas as to the way in which electrons are distributed in atoms have become crystallized more completely; and, as the result of calculations based on what is known as Fermi statistics, it is possible to calculate the average distribution of electrons in atoms. Using these calculations as a basis, Dr. Mitchell [9] has succeeded in developing a formula for the scattering of electrons by an atom, and it remains to be seen whether this formula is a more accurate representative of the facts than those formerly used by Rutherford and others.

Theory of the Compton Effect Produced by Standing Electromagnetic Waves.—Our understanding of the mechanism of atomic processes has been greatly enhanced by the discovery made by Professor A. H. Compton to the effect that when X-rays fall upon atoms, they suffer in part a change of wave-length. The relations between the wave-length of the X-rays which fall upon the atom and those which leave it after ejecting an electron are such that they could be well understood provided that we were willing to regard the X-rays as of the nature of small cannon balls possessing energy and momentum. The theory of the Compton effect was given first by Professor Compton himself on the basis of this corpuscular view as to X-rays. When the new mechanics developed, one of the most important problems which faced it was that of accounting satisfactorily for this remarkable Compton effect; and, in the hands of Schrödinger, Jordan, Dirac and others, the wave mechanics theory of the effect was developed. Now there is a certain modification of the ordinary conditions prevailing in experiments on the Compton effect, which presents an interesting question to the new wave mechanics theory. Suppose that we have two beams of X-rays coming from a source, and reflected from two suitable reflectors so as to travel superposed, but in opposite directions from left to right and from right to left respectively; and

[9] "Theory of Electron Scattering in Gases," by A. C. G. Mitchell, to be published in June 1929 issue of JOURNAL OF FRANKLIN INSTITUTE (vol. 207, 253), and *Proceedings of Natl. Acad. of Sciences.*

suppose moreover that we place in their path a thin plate of material whose atoms may be struck by the X-rays. If we should cut out the right hand beam we would, of course, get the normal Compton effect due to the left hand one, and if we should cut out the left hand beam we should get the ordinary Compton effect due to the other. But what may we expect when both beams are operating together? The old classical theory of electrodynamics does not account for any Compton effect at all, so we cannot appeal to it for an answer. The theory developed by Professor Compton on the view that the X-rays partake of the nature of particles would tell us that each of these beams act entirely independently, so that we should obtain a Compton effect corresponding to the left hand beam or to the right hand beam at any instant depending upon whether an X-ray bullet happened to arrive at that instant from the right or from the left. The new wave mechanics, however, makes a partial reversion to the older classical theory of X-rays, and pictures a set of stationary waves in the region where the opposing trains overlap. And the nature of the situation is such that it is by no means clear at a glance as to what might be expected, or indeed as to whether one might expect any Compton effect at all. Dr. Allen has attacked this problem on the basis of the new mechanics,[10] and has succeeded in reaching a solution, which shows that the results ultimately predicted in this case are exactly those which have been expected on the idea of the opposing train of waves acting independently. At the time when Miss Allen's paper was in the proof she had the satisfaction of learning of some experiments performed abroad which had completely confirmed this conclusion.

The Possibility of Detecting Individual Cosmic Rays.[11]—Considerations which time will not permit me to enter into now, show that when we take into consideration the actual magnitudes of the quantities involved, the situation as regards the ionization by cosmic rays is something like this. Suppose we consider a litre of space. Only about once in

[10] "The Scattering of a Standing Electromagnetic Wave," by M. Allen, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 207, January 1929.

[11] "The Possibility of Detecting Individual Cosmic Rays," by W. F. G. Swann, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 206, December 1928.

4000 seconds would a cosmic ray become absorbed in that litre. When it did become absorbed, if all of the ions produced by the cosmic ray were produced in the immediate vicinity of the point of absorption, we should get one tremendous spurt of five million ions, so that the situation would be one in which we got a huge spurt of 5,000,000 every hour or so and nothing between. As a practical fact, the absorption of a cosmic ray results in the production of high speed beta rays, and secondary cosmic rays which travel for considerable distances in the atmosphere and spread their ionization over a wide range, so that in our space of 1 litre capacity, the ionization produced comes from secondary radiations which have originated as the result of the absorption of cosmic rays at all sorts of different distances. There are enormously more contributions than one in each 4,000 seconds because of the very large volume which participates in ultimately supplying ionization to our one litre; but, on the other hand, the contributions to the ionization are in general small in amount because the secondary radiations producing them have suffered a great deal of spreading in their journey from the primary places of their origins; and then, even when they reach our particular litre of space, they are only partially absorbed in it. The situation is one in which the primary rays which are absorbed in regions near to the vessel give, in the vessel itself, as a result of their secondary radiations, spurts of ions large in amount but at very infrequent intervals. As regards the effect depending ultimately on cosmic rays absorbed at great distances, however, the spurts are small in amount, but frequent in occurrence on account of the large volume which contributed to the absorption of the primary rays concerned. If we confine our attention to spurts of ions which are not smaller than a certain specified amount, then we can calculate a minimum volume around our one litre from which they must have come, and we can calculate the number of spurts which may be expected as the result of the absorption of primary rays in this volume. When everything is submitted to calculation, it turns out that it should just be possible to record in a vessel of the order of one litre capacity pumped up to a high pressure, the separate spurts of ionization due to individual cosmic rays,

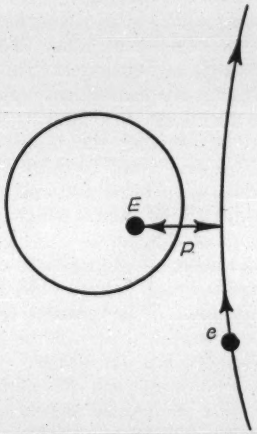
and I am hoping that we may be able to seek experimentally for these spurts in the near future. If we find them, they will be perhaps among the most definite evidence obtainable for the reality of the rays and for the character which has been attributed to them.

The Relation between Mass and Energy.—It is one of the triumphs of theoretical physics that we have come to realize a very close connection between mass and energy. It has for long been a familiar concept, arising from electrodynamics and from the theory of relativity, that the mass of an electron depends upon its velocity, increasing with the velocity until it finally attains an infinite value, when the electron attains a velocity equal to the velocity of light. The change of mass of the electron is exactly proportional to the change of energy, and is such that when multiplied by the square of the velocity of light, it equals the change of energy. Now this idea has been extrapolated far beyond the region which originally gave it birth; and we have come to think of a very complete interchangeability between mass and energy. For example, we have come to think of the energy which has to be provided to maintain the heat of the sun as coming from the mutual annihilation of the masses of protons and electrons resulting from their running into each other. The energy obtainable in this way is enormous. The protons and electrons in a single drop of water, would, if allowed to commit suicide in this manner, provide 200 h.p. for a year.

While the increase of mass with the energy associated with the velocity has quite a definite significance in electrodynamics, I have never felt quite satisfied as to the logical extension of the relation between mass and energy to a case such as that contemplated in the annihilation of a proton and an electron, and I have consequently been interested in formulating on what appears to be a more rigorous basis, the sense in which the quantity which we call and measure as the mass of the electron may be regarded as the representative of electromagnetic energy. The details of this analysis, involving as they do, transformations of the theory of relativity, are much too involved for presentation in a few minutes, and I fear I must refrain from saying anything more about the matter.

The Ionization Producible by an Electron Travelling with a Speed Comparable with that of Light. The importance of this problem lies in its relation to theories of the origin of the earth's charge. Any theory which is to account for the replenishment of the earth's charge by electrons shot into it, has to provide for about 1500 electrons shot into each square cm. per second, and we might expect such electrons to produce very large amounts of ionization in the atmosphere. The situation is this; an electron with a speed approximating that

FIG. 25.



of light produces about 40 pairs of ions per centimeter of path, so that in each cubic centimeter we might expect ions to be produced to the extent of about 60,000 per cc. per second, whereas experiment shows that they are only produced to the extent of 1/10,000 of this amount. In order to see how we may escape from this difficulty, it may be of interest to probe a little more closely into the mechanism of the ionization; and let us first consider the matter from the standpoint of classical electrodynamics.

Suppose *E*, Fig. 25, is an electron in an atom, and that another electron *e*, which I shall distinguish by calling it a

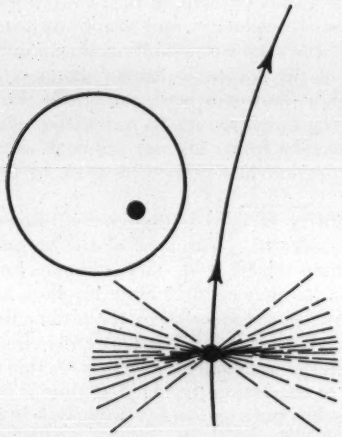
corpuscle, approaches the atom. The corpuscle will start to repel the electron as it approaches, and will continue to do so as it recedes, with the result that the electron receives energy, the momentum which it acquires being more or less in a direction perpendicular to the line of flight of the corpuscle. The greater the velocity of the corpuscle, the shorter the time during which the electron has opportunity to receive momentum from it. The efficiency of the corpuscle as regards its power to hurl the electron out of the atom thus diminishes with increase of its velocity, and would, as a matter of fact, become zero if the corpuscle could attain an infinite velocity. The velocity of the corpuscle cannot attain a value greater than that of light, however, and, as regards the above effect, there is not very much reduction in ionizing efficiency for an increase of velocity from, say, 95 per cent. of that of light, where the ionization has been measured, to the velocity of light itself.

As the velocity of light is approached, however, another phenomenon comes in. The field of the corpuscle does not remain uniformly distributed According to known electromagnetic laws, its lines of force close up more and more into its equatorial plane, as indicated by the broken lines in Fig. 26. The time which the corpuscle has for acting effectively on the electron is therefore reduced still further on this account; but, the intensity, of the action during that time is increased; and it turns out, as has been shown by Bohr, that if we take nothing else into consideration, the energy communicated to the electron by the passage of the corpuscle will be unaffected by this concentration of the lines of force.

There is one other very important consideration which we must take into account, however. If an electron receives even a small velocity in a very short time, it is known that it will radiate a large amount of energy. Its sudden start results in a violent jerk in the æther. On submitting this matter to calculation it turns out that, even if we should wish to give to an electron but a small amount of energy, in an infinitesimal time, it would be necessary to pay a sort of tax of an infinite amount of energy in the shape of radiation. Now the more nearly the corpuscle approaches the velocity of light, the more suddenly does it communicate to the

electron such energy as it imparts. Without entering too greatly into details, we may describe the situation as follows: In the case of a corpuscle moving with a velocity approximating that of light (say 95 per cent. of the velocity of light), but not so closely as to involve these radiation considerations, it turns out that the corpuscle must approach an electron of an oxygen atom within 0.7×10^{-10} cm., in order that it shall be

FIG. 26.



able to eject that electron from the atom. If the minimum distance of approach is less than this amount the energy imparted to the electron will be greater, if it is more, the energy imparted to the electron will be less. It is, however, possible to assign to the corpuscle a velocity so high that, irrespective of the distance of approach, if we should suppose it to transmit to the electron an amount of energy corresponding to the ionization potential of oxygen (15.5 volts), we should lead ourselves to the impossible conclusion that the electron's acceleration would be so large that the energy radiated by it in acquiring its velocity would be greater than the work done on it by the corpuscle. Thus corpuscles having the velocity in question, or any higher velocity, would

be unable to eject an electron from an atom of oxygen, the more easily ionizable of the two main constituents of the atmosphere.[12] When we work out this velocity, we find that it comes out as only 45 metres per second less than the velocity of light. In spite of the very close approximation of the velocity to the velocity of light, the value found happens to be exactly the velocity which Birkeland has found it necessary to assign to solar corpuscles if the bending which these corpuscles suffer in the earth's magnetic field is to be consistent with their accounting for the aurora. Corpuscles of lower speeds would suffer in the earth's magnetic field deviations too large to permit of their accounting for the facts. The diminution of bending, resulting from approximation of the velocity to that of light, results not so much from the direct influence of high speed as from the increase in the mass of the corpuscle which approximation to the velocity of light implies.

Now, tempting as this theory may seem, it is not without its difficulties. For, the laws which govern the radiation of energy by accelerated electrons become of doubtful applicability when that acceleration is produced by another electron which is travelling with a speed as high as those to which I refer. For, under these conditions, the field of the rapidly moving electron is so nearly concentrated to a plane, that it varies very considerably over the volume of the electron on which it is acting. I pointed out these matters very carefully in the paper which I wrote on this subject some years ago, and while I have the satisfaction of knowing that many people have accepted the theory which I propounded, none of them seemed to pay any particular attention to the criticism which I myself raised against it, in the appendix to the paper in which I presented it. I do not know whether to be elated or depressed over this situation! Now, unfortunately, or fortunately, the state of electromagnetic theory at the time when I wrote this paper was such that there did not exist the possibility of giving what I would have called a logically exact answer to the problem. Now, however, the new wave mechanics places us in a different situation, and I am hoping

[12] The complete theory of this matter was developed in a paper "The Absence of Ionization by Electrons with Speeds Comparable with that of Light," W. F. G. Swann, *Phil. Mag.*, S. 6, Vol. 47, pp. 306–319, 1924.

that it may be possible to tell the story of what happens when a very rapidly moving corpuscle of this kind endeavors to eject an electron from an atom. Miss Allen is at work upon the matter, and if she is successful in reaching a solution, we shall be very much more at ease as regards this very fundamental problem.

Physics and Vital Processes.[13]—It is characteristic of the present era of knowledge that we have reached a situation in which the various departments of science no longer hold aloof from each other. We are nearing the fundamentals in many branches, and ultimately, the fundamentals must be the same for all. In particular, our knowledge of the facts of biology has reached a stage where we must look in large part to the fundamentals of physics for further processes. During the last year it became necessary for me to turn my attention for a time to some of these matters, in particular, with a view to crystallizing what it seemed to me must constitute some of the fundamental distinctions between the laws which characterize living and non-living matter. I am well aware of the breadth of the problem, and of the fact that it is not the sort of thing which can be dismissed with a few thoughts; and, had I the time I should spend one-third of this lecture apologizing for the fact that I, a physicist, should think about it at all, and the rest of the lecture would have to be spent expounding what I had to say. I fear it is quite impossible for me to attempt any digest of the conclusions which I have reached. If anyone wishes to raise any points in this matter in the discussion I shall do my best to answer them. For the present, I must content myself with saying that it seems to me, at any rate, that modern physics has a place for those phenomena which we associate with life,—for free will, for heredity, for the mind, for thought and so forth, and I think that even in non-living matter we can see in primitive form, some of those very characteristic features which in their more exaggerated forms we associate with the living state. Even in an atom we can find free will, and free will controlled by the influence of its neighbors.

Then, in passing, I may cite two other theoretical investi-

[13] The full account of these considerations is published in *Science*, "Physics and Vital Processes," by W. F. G. Swann, Vol. 68, pp. 411–419, Nov. 2, 1928.

gations, one by Dr. Bramley[14] having to do with the laws which govern the motion of an electron, on the new wave mechanics; and another by myself[15] on the fundamentals of wave mechanics. Both of these are too involved for presentation in brief forms.

And now my time is drawing rapidly to a close—I fear that only a negative amount of it remains, but I should like to end with a few words concerning the significance of all investigations in pure science. We sometimes hear the question asked, "What is the use of theorizing in physics—in trying to find out how nature works? Let us get down to something practical, something which will show immediate results." The complete answer to this question would take a lot of time; but, I may perhaps say that there are two types of discovery, one in which somebody discovers by accident or otherwise, some new phenomena, or substance, which over night, revolutionizes some process or branch of science. Then there is the other type of discovery whose significance I can perhaps symbolize in this way.

Suppose that I should go into a new country, with whose laws I were unfamiliar. I should proceed to violate the traffic regulations and get locked up. I should seek to buy a house, and should make many mistakes, and finally muddle my way to a completion of the transaction. I should seek to raise a loan and should encounter many embarrassing and time-wasting considerations. And then, perchance, I should sit down and say to myself "It is about time that I found out what the laws of this country are." Suppose that the situation were such that I could not inquire as to this matter from the local authorities, but were compelled to find it out for myself. On the basis of my experience of being arrested for speeding, and of buying a house, and of a dozen other things, I might formulate some system of laws for that country which would correlate those things which had happened to me. These laws would then suggest other things which might be true—they might suggest that prohibition

[14] "Schrödinger Dynamics," by A. Bramley, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 206, November 1928.

[15] "Wave Mechanics," by W. F. G. Swann, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 207, April 1929.

would be likely to exist in this country, or that smoking were prohibited, or possibly required; and if the theory I had formulated were a good one, it would not lead me into error in these speculations. There is a very good chance that if I had pinned it down to known facts at the places where I knew those facts, it would be faithful and tell me no false story at other places where I asked information of it. Now, on the basis of the more complete knowledge of the laws of this country thus obtained, I should be in a very much better position to make use of them and develop the resources available to me as a result of this more complete sensitivity to the way in which things happened. There would, in the course of five, ten or fifteen years, arise railroads in that country, there would arise telephones, there would arise huge factories, and various other things, so that in comparison with the situation which existed at the beginning of that time, we might in all verity say that a miracle had happened; and yet these things would have arisen in such manner that there was no particular occasion on which anyone would go to bed at night, and arise on the following morning to find things appreciably different from what they were the night before. It is in some such sense, as I have endeavored here to picture, that a great generalization in mathematical physics can serve a practical use in the realms of science.

BARTOL RESEARCH FOUNDATION,
May 12, 1929.

THEORY OF THE CHARGING EFFECT ON AN INSULATED BODY EXPOSED TO PRIMARY CORPUSCULAR RADIATION OR TO CORPUSCULAR RADIATION INITIATED BY THE COSMIC RADIATION.

BY

W. F. G. SWANN, D.Sc.,

Director of the Bartol Research Foundation.

BARTOL RESEARCH FOUNDATION
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Introduction.—The chief interest of the present paper lies in its relation to the preceding paper by W. F. G. Swann and A. Longacre.[1] The most obvious picture of a charging process is one in which a primary stream of electrons descends upon the earth from outside the atmosphere. The less obvious method is one invoking the cosmic radiation as a primary agent, the function of the cosmic radiation being to eject electrons from the atoms of the air with great speed with the result that the insulated body becomes exposed to a bombardment of electron radiation.

Charging by Primary Corpuscular Radiation.—Suppose the number of electrons falling on the element ds of the absorbing body per second, and having come from within the solid angle $d\omega$ is

$$A \cos \alpha \, d\omega \, ds \qquad (1)$$

where α is the angle between the normal to the element ds and the axis of $d\omega$, and A is a constant, or possibly a function of θ, the angle between the axis of $d\omega$ and the vertical.

If the electrons came into the outer atmosphere equally in all directions and then suffered absorption in the atmosphere according to an exponential law with coefficient β for standard pressure, the value of A would be

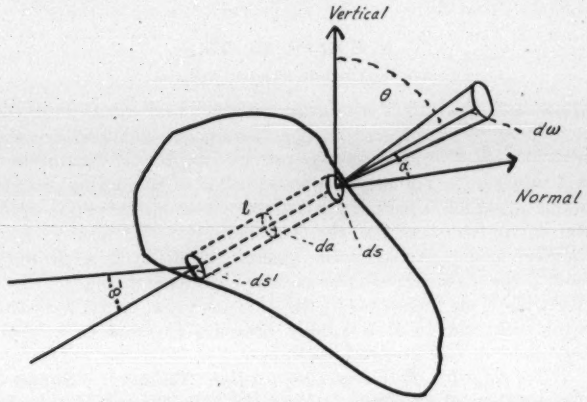
$$e^{-\frac{\beta h}{\cos \theta}} \qquad (2)$$

where h is the height of the homogeneous atmosphere above the point considered.

[1] "An Endeavor to Detect a Corpuscular Current Entering the Earth," JOUR. OF THE FRANKLIN INST., this issue, page 275.

Let us draw a cylinder bounding ds, penetrating the solid, and emerging at ds', the axis of the cylinder being parallel to that of $d\omega$. Then, if β' is the coefficient of absorption of the corpuscles in the solid, the number emerging from ds', per

FIG. 1.



second, after having approached it within a solid angle equal to $d\omega$ is

$$Ae^{-\beta' l} \cos \alpha' d\omega ds', \tag{3}$$

where α' is the angle between the normal to ds' and the axis, of $d\omega$, and l is the length of path between ds and ds'.

Now if da is the cross section area of the cylinder,

$$da = \cos \alpha ds = \cos \alpha' ds',$$

so that the difference between (1) and (3) gives

$$Ad\omega da[1 - e^{-\beta' l}]. \tag{4}$$

If β' is small, as it would have to be if the foregoing experiments were to be consistent with an influx of corpuscles sufficient to account for the maintenance of the earth's charge, we may expand the exponential, and write (4) as

$$A\beta' l d\omega da. \tag{5}$$

Remembering that lda is the volume dv of the elementary cylinder, (5) becomes

$$A\beta' dv d\omega. \qquad (6e$$

Let us take a vertical axis of polar coördinates θ and φ on each element ds of the surface, and confine our attention for each of these elements to the solid angle $d\omega$, specified by the limits θ, φ, $\theta + d\theta$, $\varphi + d\varphi$. Then (6) becomes

$$A\beta' \sin \theta d\theta d\varphi dv.$$

Let us sum for all the elements ds. Then, the absorption of electrons per second resulting from those falling on their respective elements ds within the ranges θ, φ, and $\theta + d\theta$, $\varphi + d\varphi$, is

$$A\beta' v \sin \theta d\theta d\varphi.$$

where v is the volume of the solid.

Integrating now for all values of θ and φ, we have for the total absorption of electrons per second, by the solid,

$$n = 2\pi\beta' v \int_0^{\pi/2} A \sin \theta d\theta.$$

On the other hand, the total number of electrons entering one square centimeter of the earth's surface per second is

$$N = 2\pi \int_0^{\pi/2} A \sin \theta \cos \theta d\theta.$$

Hence

$$\frac{n}{N} = \beta' v \frac{\int_0^{\pi/2} A \sin \theta d\theta}{\int_0^{\pi/2} A \sin \theta \cos \theta d\theta}.$$

Inserting the value of A given by (2) and changing the variable from θ to $x = 1/\cos \theta$, we have

$$\frac{n}{N} = \beta' v \frac{\int_1^{\infty} \frac{e^{-\beta h x}}{x^2} dx}{\int_1^{\infty} \frac{e^{-\beta h x}}{x^3} dx}.$$

Now

$$\int_1^\infty \frac{e^{-\beta hx}}{x^3}dx = \left[\frac{e^{-\beta hx}}{2x^2}\right]_\infty^1 - \frac{\beta h}{x^2}\int_1^\infty \frac{e^{-\beta hx}}{x^2}dx.$$

Hence,

$$\frac{n}{N} = \beta' v \frac{\int_1^\infty \frac{e^{-\beta hx}}{x^2}dx}{\frac{1}{2}e^{-\beta h} - \frac{\beta h}{2}\int_1^\infty \frac{e^{-\beta hx}}{x^2}dx}. \qquad (7)$$

Now, the assumption of a corpuscular current sufficient to maintain the earth's charge would, when taken in conjunction with the experimental evidence of the preceding paper, necessitate [2] that the left hand side of (7) must be less than $3{\cdot}7 \times 10^{-7}/5{\cdot}5 \times 10^{-7}$.

Hence, writing

$$I = \int_1^\infty \frac{e^{-\beta hx}}{x^2}dx$$

$$\frac{3{\cdot}7}{5{\cdot}5} > \frac{2\beta' vI}{e^{-\beta h} - \beta hI}.$$

If we write $\beta'/\beta = Dc/Da$, where Dc and Da refer respectively to the densities of copper and air, we have

$$\frac{3{\cdot}7}{5{\cdot}5} > \frac{2vD_c}{hD_a}\frac{I}{\frac{e^{-\beta h}}{\beta h} - I},$$

which leads to

$$pI < \frac{e^{-p}}{1 + \frac{3vD_c}{hD_a}}, \qquad (8)$$

where

$$p = \beta h.$$

Now

$$I = \int_1^\infty \frac{e^{-px}}{x^2}dx = p\int_p^\infty \frac{e^{-\epsilon}}{\epsilon^2}d\epsilon.$$

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[2]

Put

$$\epsilon = \eta + p,$$

$$I = pe^{-p}\int_0^\infty \frac{e^{-\eta}d\eta}{(\eta+p)^2}$$

$$= pe^{-p}\left\{\left[-\frac{e^{-\eta}}{\eta+p}\right]_0^\infty - \int_0^\infty \frac{e^{-\eta}}{\eta+p}d\eta\right\},$$

$$I = e^{-p} - pe^{-p}J, \tag{9}$$

when

$$J = \int_0^\infty \frac{e^{-\eta}\,d\eta}{\eta+p}$$

$$= \int_0^\infty \frac{e^{-p\zeta}}{1+\zeta}d\zeta;$$

hence, since $e^{p\zeta} > 1 + p\zeta$,

$$J < \int_0^\infty \frac{d\zeta}{(1+p\zeta)(1+\zeta)}$$

$$< \frac{1}{1-p}\left\{\int_0^\infty \frac{d\zeta}{\zeta+1} - \int_0^\infty \frac{d\zeta}{\zeta+1/p}\right\}$$

$$< \frac{1}{1-p}\left[\log\frac{\zeta+1}{\zeta+1/p}\right]_0^\infty < \frac{1}{p-1}\log p.$$

Hence, returning to (9),

$$e^{-p} - I < \frac{pe^{-p}}{p-1}\log p.$$

Hence

$$e^{-p}\left[1 - \frac{p}{p-1}\log p\right] < I.$$

Hence, from (8),

$$p\left(1 - \frac{p}{p-1}\log p\right) < \frac{1}{1+\frac{3vD_e}{hD_a}}.$$

hD_a is the atmospheric pressure in grams per sq. cm., i.e. 13.6×76, and taking $D_e = 9.0$, and for v, the volume of

the cylinder as calculated from its diameter 20.6 cm. and its height 19.3 cm., the value $v = 6500$, we find

$$\frac{1}{1 + \frac{3vD_e}{hD_a}} = 0.6 \times 10^{-2}.$$

On plotting $p[1 - p/(p - 1) \log p]$ against p, we find that it decreases with decrease in p, and attains the value 0.6×10^{-2} at $p = 0.7 \times 10^{-2}$, so that

$$p < 0.7 \times 10^{-2}.$$

Since $p = \beta h$, putting

$$h \times 0.00129 = 76 \times 13.6$$

so that $h = 8 \times 10^5$, we have

$$\beta < 9 \times 10^{-9},$$

which represents a radiation 28 times as penetrating as the most penetrating cosmic rays found by Millikan and Cameron, and 6000 times as penetrating as the gamma rays from Radium C. Such then, is the penetrating power which must be invoked for the corpuscles if they are to account for the maintenance of the earth's charge and at the same time, fail of detection in the experiments here described. The natural inference is that it is unreasonable to look to a primary radiation of this type as an origin for the maintenance of the earth's charge.

Charging through the Influence of Cosmic Radiation.—The problem presents certain difficulties from the outset. It is probably correct to consider a quantum of primary cosmic radiation as passing through the atmosphere unchanged until it ejects an electron from an atom, in which case we have, in addition to the ejected electron, a secondary quantum which is of longer wave-length in accordance with the principles of the Compton effect. Moreover, the law as to variation of intensity with direction applicable for the primary cosmic radiation becomes lost, or at any rate modified to a more complicated form, in the case of the secondary radiation.

A secondary quantum then passes through the atmosphere unchanged until it suffers an " encounter " with an electron, when again it ejects that electron from the atom and gives birth to a new quantum which is still further softened by the Compton effect. We thus have to consider separate groups of electrons ejected from the atmosphere by these various orders of cosmic radiation. Then, strictly speaking, any one of these groups of electrons acts in a rather complicated way as regards what we may crudely term its absorption. In the first place, any one of these electrons does not suffer a " collision " with an atom in the sense that two billiard balls may be said to collide, nor does it suffer a disappearance into the atom. There are all sorts of encounters ranging from an infinitesimal deflection of path; and, the phenomenon of absorption is a very complicated one in which many deflections of path and losses of velocity take place until the electron, originally of high speed, is brought down to a velocity where it is captured by an atom. If the electrons all originated with equal velocity, and if the velocity remained unchanged until the act of the ultimate absorption, we could justify an exponential law for the number of electrons which travel more than an assigned distance r from the point of origin; but, even then, the utilization of this law would be attended with difficulties in view of the varied and unknown directions of emission of the electrons from the atoms. It is, of course, true that many of the difficulties apply also to the problem we have already considered in connection with primary radiation, but the situation was there simplified at least to the extent that the initial directions of the electrons were specified.

In order to alleviate some of the difficulties to which we have referred, we shall commence by considering that group of electrons which is emitted by the primary cosmic radiation, and we shall afterwards extend our consideration to the electrons emitted by the secondary and higher order cosmic radiations.

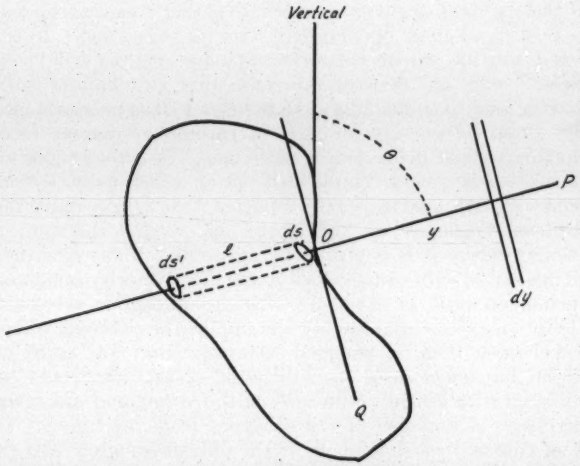
The number dM of primary cosmic rays, of any assigned frequency crossing, in one second, one square centimeter, perpendicular to their path which we shall suppose parallel to a line OP whose polar coördinates fall between θ and

$\theta + d\theta$, φ and $\varphi + d\varphi$ is

$$dM = B_0 e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi, \tag{10}$$

where θ is measured from the vertical, h is the height of the homogeneous atmosphere above the point considered, and

FIG. 2.



B_0 is a constant determined by the condition that the number M_0 of cosmic rays passing one horizontal square centimeter per second is

$$M_0 = 2\pi B_0 \int_0^{\pi/2} e^{-\lambda h/\cos\theta} \sin\theta \cos\theta d\theta,$$

so that, on writing $\cos\theta = 1/x$

$$B_0 = \frac{M_0}{2\pi \int_1^\infty \frac{e^{-\lambda h x}}{x^3} dx}. \tag{11}$$

Let us divide the absorbing body into elementary cylinders with their axes parallel to the line OP. Consider a pair of

planes perpendicular to OP, separated by a distance dy, and at a perpendicular distance y from some element of area ds of the surface of the body. The amount of cosmic radiation passing per square centimeter per second through the planes at y, within the limits specified by $d\theta$ and $d\varphi$ is given by (10), and the amount of it absorbed within the distance dy is $\lambda dMdy$, so that ΔP_0, the number of electrons emitted from one square centimeter of the pair of parallel planes is

$$\Delta P_0 = g\lambda dMdy = g\lambda B_0 e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi dy, \qquad (12)$$

where g is a constant.

Now the electrons emitted between the planes separated by dy do not all travel parallel to OP. However, the number of electrons which succeed in crossing one square centimeter of some other plane Q parallel to, and at a distance γ from, the planes separated by dy is the same for all points of the plane Q, and is of the form

$$\Delta P = \Delta P_0 f(\gamma),$$

where $f(\gamma)$ is some unknown function of γ. While it would doubtless be erroneous to suppose the $f(\gamma)$ was an exponential in γ, it is probably permissible to write it as the sum of a number of exponentials, so that the number of the electrons reaching the element of surface ds, whose projection perpendicular to OP we shall suppose equal to da, may be written as $\Delta P da$ where

$$\Delta P = \Delta P_0 \{b_1 e^{-\beta_1 \gamma} + b_2 e^{-\beta_2 \gamma} \cdots\}. \qquad (13)$$

We suppose that the b's are constants independent of the nature of the medium, and that the β's are proportional to the density of the medium. These assumptions amount to supposing that the number of electrons absorbed per square centimeter from a stream of electrons in passing across the space between two parallel planes, is determined entirely by the mass of matter per square centimeter between those planes. Incidentally, it may be noted that the constants b must satisfy the condition

$$b_1 + b_2 \cdots = 1,$$

since $\Delta P = \Delta P_0$ when the β's are zero.

Thus, if dn is the number of electrons absorbed per second through the element ds, as a result of having been ejected by the primary cosmic radiation travelling in a direction specified by the limits θ to $\theta + d\theta$ and φ to $\varphi + d\varphi$, and from the space lying between planes at a distance y from ds and separated by dy, we have, using (12) and (13) [3]

$$dn = g\lambda B_0 e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi da dy \sum_n b_n e^{-\beta_n y} dy. \qquad (14)$$

Integrating for all values of y, we have for Δn, the total influx of electrons to the element ds of the body as a result of the action of the primary cosmic radiation travelling within the specified limits,

$$\Delta n = g\lambda B_0 e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi da \sum_n \frac{b_n}{\beta_n}. \qquad (15)$$

We have here assumed that the electrons are much more absorbable than the cosmic radiation, so that we have been able to neglect the variation of h over the effective range of integration for y. We have also assumed that no electrons pass right through the body.

We must now consider the number of electrons shot out of the body from the body itself by the cosmic radiation.

If ds' refers to the element of area at the lower end of the elementary cylinder whose upper element of area is ds, the number of quanta of cosmic radiation travelling within the assigned limits and passing per second per square centimeter through a point in the vicinity of ds' is

$$B_0 e^{-\lambda h/\cos\theta} e^{-\lambda' l} \sin\theta d\theta d\varphi,$$

where λ' refers to the coefficient of absorption of the cosmic rays in the substance of the body, and l is the length of the elementary cylinder.

Following an argument similar to that used for the electrons shot into the body, we have for $\Delta n'$, the number of electrons emerging per second through ds' on account of the

[3] There is a slight error as regards the contribution to the integral from regions quite near to ds; for, a pair of parallel planes drawn at a distance apart dy, and very near to ds would obviously, in general, intersect the body. The error in this connection is purely formal however, and negligibly small.

cosmic radiation travelling within the prescribed limits, the value

$$\Delta n' = g\lambda' B_0 e^{-\lambda h/\cos\theta} e^{-\lambda' l} \sin\theta d\theta d\varphi da \sum \frac{b_n}{\beta_n'}, \qquad (16)$$

where β_n' is the quantity which corresponds for the body to the quantity β_n for air.

Thus, as regards the contribution of the elementary cylinder in question to the net absorption of electrons by the body as a result of the radiation specified, we have [4]

$$\Delta n - \Delta n' = gB_0 e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi \left[\lambda' e^{-\lambda' l} \sum \frac{b_n}{\beta_n'} - \lambda \sum \frac{b_n}{\beta_n} \right] da. \qquad (17)$$

Now, if we recall our assumption that the β's are proportional to the density of the substance, and if we further assume that the coefficient of absorption of the cosmic radiation is proportional to the density of the substance, we have

$$\lambda' \sum \frac{b_n}{\beta_n'} = \lambda \sum \frac{b_n}{\beta_n},$$

so that

$$\Delta n - \Delta n' = gB_0 e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi [e^{-\lambda' l} - 1] \lambda da \sum \frac{b_n}{\beta_n}.$$

If we now assume that the absorption of the cosmic radiation in the body is sufficiently small to warrant writing

$$e^{-\lambda' l} = 1 - \lambda' l$$

we have

$$\Delta n - \Delta n' = gB_0 e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi \lambda\lambda' l da \sum \frac{b_n}{\beta_n}.$$

[4] In considering the electrons emerging from any elementary cylinder there becomes involved the fact that when the wave normal is inclined to the normal to the surface at the point, a certain error arises in the calculated emergence radiation on account of the fact that the plane of the cosmic ray waves cannot be produced practically to infinity in all directions without passing out of the body. The error is small if the electrons are emitted for the most part in the direction of the cosmic radiation.

If we now sum for all the elementary cylinders of the body whose axes are parallel to the normal to the radiation, and if we observe that $\Sigma lda = v$ where v is the volume of the body, we have for δn, the net number of electrons absorbed per second by the body as a result of the action of the cosmic radiation falling within the specified limits

$$\delta n = \lambda\lambda' v g B_0 e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi \sum \frac{b_n}{\beta_n}.$$

The net absorption of electrons per second as a result of primary cosmic radiation coming from all directions is thus

$$n = \lambda\lambda' v g B_0 \sum \frac{b_n}{\beta_n} \int_0^{\pi/2} \int_0^{2\pi} e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi. \qquad (18)$$

Now, remembering that the normal to the projected element da of equation (14) is inclined at an angle θ to the normal to the earth, it may be seen immediately from that equation that the number of electrons absorbed per second per square centimeter of the earth is

$$N = \lambda g B_0 \sum \frac{b_n}{\beta_n} \int_0^{\pi/2} \int_0^{2\pi} e^{-\lambda h/\cos h} \sin\theta \cos\theta d\theta d\varphi. \qquad (19)$$

Integrating with regard to φ, transforming the integrals by writing $\cos\theta = 1/x$ and dividing (18) by (19) we obtain

$$\frac{n}{N} = \lambda' v \frac{\int_1^\infty \frac{e^{-\lambda h x}}{x^2} dx}{\int_1^\infty \frac{e^{-\lambda h x}}{x^3} dx}.$$

If D_a and D_c are the densities of air and of the body respectively, we have

$$\frac{n}{N} = \frac{D_c}{D_a} \lambda v \frac{\int_1^\infty \frac{e^{-\lambda h x}}{x^2} dx}{\int_1^\infty \frac{e^{-\lambda h x}}{x^3} dx}. \qquad (20)$$

If the primary cosmic radiation had come in equally at all angles instead of according to the law expressed by (10), the

effect would have been to replace the exponentials in (20) by constants, and in this case the ratio of the integrals would be $1/0.5 = 2$. Considering the two integrals in (20) as sums, with the exponentials as factors to each sum, we see that the effect of the exponentials is to enhance the importance of the contributions to the integrals in the neighborhood of $x = 1$ in relation to the contributions for higher values of x, and so to tend to make the ratio of the integrals more nearly equal to unity than when the exponentials are absent. The secondary cosmic radiation and the cosmic radiation of all orders higher will be more equally oriented than the primary radiation, so that the value of n/N for the electrons corresponding to any one of the higher order radiations will be of the form

$$\frac{n_r}{N_r} = \frac{D_c}{D_a}\lambda_r v T,$$

where λ_r refers to the coefficient of absorption of the rth order radiation, and where

$$2 > T > \Sigma \frac{\int_1^\infty \frac{e^{-\lambda h x}}{x^2}\,dx}{\int_1^\infty \frac{e^{-\lambda h x}}{x^3}\,dx}.$$

Thus

$$\frac{n_r}{N_r} \geq \frac{D_c}{D_a}\lambda_r v \Sigma \frac{\int_1^\infty \frac{e^{-\lambda h x}}{x^2}\,dx}{\int_1^\infty \frac{e^{-\lambda h x}}{x^3}\,dx}.$$

Since λ for the primary radiation is less than λ_r for any higher order, we see that n/N is less than the value n_r/N_r for any $r > 1$. Thus

$$\frac{\Sigma n_r}{\Sigma N_r} > \frac{n}{N}.$$

Hence

$$\frac{\Sigma n_r}{\Sigma N_r} > \frac{D_c}{D_a}\lambda v \Sigma \frac{\int_1^\infty \frac{e^{-\lambda h x}}{x^2}\,dx}{\int_1^\infty \frac{e^{-\lambda h x}}{x^3}\,dx}. \qquad (21)$$

and since the ratio of the integrals is greater than unity for any λ,

$$\frac{\Sigma n_r}{\Sigma N_r} > \frac{D_c}{D_a}\lambda v.$$

Even if we take for λ the least value assigned by Millikan and Cameron,[5] i.e. $\lambda = 26 \times 10^{-8}$ for air at atmospheric pressure, and if we put in the value $v = 6500$ as corresponds to the experiment described in the preceding paper, and $D_c = 9.0$ and $D_a = 0.0013$, we find

$$\frac{\Sigma n_r}{\Sigma N_r} > 12.$$

According to the results already quoted, and corresponding to the experiments of the preceding paper, however,

$$\frac{\Sigma n_r}{\Sigma N_r} < \frac{3.7}{5.5}.$$

Hence we conclude that the corpuscular current cannot be accounted for as an indirect result of the action of the cosmic radiation unless we assume a primary radiation of enormously higher penetrating power than any so far found, and of correspondingly high intensity sufficient to account for the charging effect.

Considerations from the Standpoint of Cosmic Ray Energy.—According to the calculations of Millikan and Cameron, the cosmic ray energy entering our atmosphere is 3.07×10^{-4} ergs per square centimeter. This corresponds to the amount of energy necessary to give 1 electron 200 million volts velocity.

Now the replenishment of the earth's charge by corpuscular radiation necessitates an influx to earth of about 1500 electrons per square centimer per second. Hence, even if all the cosmic ray energy entering the atmosphere could be supposed concentrated into those particular electrons

[5] Of course $\Sigma n_r/\Sigma N_r$ increases with λ but by postulating the least possible λ, and of course, admitting therefore, implicitly, a sufficient intensity of the radiation to account for the atmospheric electric current, we assign the most favorable conditions for an absence of measurable charging effect in the present experiment.

which enter the earth, leaving nothing for those which are ejected from higher regions of the atmosphere and stopped by the atmosphere in their downward flight, there would only be energy corresponding to about 130,000 volts for each electron.

In accordance with (12), the number of electrons emitted per unit of volume corresponding to the cosmic rays defined by the limits θ to $\theta + d\theta$ and φ to $\varphi + d\varphi$ is

$$g\lambda B_0 e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi \qquad (22)$$

and the total number of electrons freed per cc. per second is

$$q = g\lambda B_0 \int_0^{\pi/2}\int_0^{2\pi} e^{-\lambda h/\cos\theta} \sin\theta d\theta d\varphi. \qquad (23)$$

Thus, making the substitution $\cos\theta = 1/x$ and combining (19) and (23), we have

$$\frac{q}{N} = \frac{\int_1^\infty \frac{e^{-\lambda h x}}{x^2} dx}{\Sigma \frac{b_n}{\beta_n}\int_1^\infty \frac{e^{-\lambda h x}}{x^3} dx} = \frac{R}{\Sigma \frac{b_n}{\beta_n}},$$

where R is the ratio of the integrals.

Now, in order to account for the replenishment of the earth's charge, we must have $N = 1500$ electrons per square centimeter per second. Moreover, q cannot be greater than 10, the total number of ions produced per c.c. per second in the atmosphere from all causes.

Hence

$$\Sigma \frac{b_n}{\beta_n} > \frac{1500}{10} R.$$

Since $R > 1$, we have

$$\Sigma \frac{b_n}{\beta_n} > 150.$$

If we define a sort of average β_0 by the relation

$$\frac{1}{\beta_0}\Sigma b_n = \Sigma \frac{b_n}{\beta_n};$$

then, remembering that $\sum b_n = 1$, we have

$$\frac{1}{\beta_0} = \sum \frac{b_n}{\beta_n}.$$

Thus

$$\frac{1}{\beta_0} > 150.$$

In other words, the apparent mean free path of these electrons must be greater than 150 cms., a result quite inconsistent with their having velocities corresponding to as little as 130,000 volts.

Thus, energy considerations alone would force us to conclude that if the replenishment of the earth's charge comes about by corpuscular radiation shot into the earth by the cosmic radiation, it is necessary to assume a much greater energy flux of cosmic radiation than has been observed. To this conclusion we add the further conclusion deduced above, and resulting from the foregoing theoretical interpretation of the results quoted in the preceding paper, to the effect that replenishment of the earth's charge by this means would involve the existence of a cosmic radiation of penetrating power far greater than any observed. Finally, we may add the conclusion reached in the first part of the present paper, to the effect that if the replenishment occurs through the agency of a primary corpuscular radiation coming from outside our atmosphere, the experimental results of the preceding paper demand for it a penetrating power 28 times as great as that of the most penetrating cosmic radiation recorded by Millikan and Cameron.

AN ENDEAVOR TO DETECT A CORPUSCULAR CURRENT ENTERING THE EARTH.*

BY

W. F. G. SWANN, D.Sc.,

Director of the Bartol Research Foundation.

and

A. LONGACRE,

Research Assistant.

BARTOL RESEARCH FOUNDATION.
Communication No. 40.

THE present investigation is an extension of an earlier investigation made by one of us[1] on "An Attempt to Detect a Corpuscular Radiation of Cosmic Origin."

The possibility that our earth is continually bombarded by high speed negative electrons is one which has a bearing on various phenomena concerned with atmospheric electricity. In the form in which it is least open to theoretical difficulties the corpuscular radiation is supposed to arise as a result of the ejection of electrons from our atmosphere through the agency of the cosmic radiation; and, in this form, E. von Schweidler[2] and one of the present writers[3] have invoked it to account for the maintenance of the earth's charge. Such a corpuscular radiation might reasonably be expected to produce a charging effect in an insulated body exposed to it, unless indeed the radiation is so penetrating as to pass right through. However, in case the corpuscles are ejected through the agency of the cosmic radiation, we might expect that the influx of corpuscles from the atmosphere would be to some extent compensated by an ejection of corpuscles from the insulated body

* This investigation was carried out at Cornell University during the summer of this year, during the period in which one of the writers was lecturing at the University. The writers desire to express their thanks to the Department of Physics for the facilities afforded.

[1] W. F. G. Swann, JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 203, pp. 11–33, 1927.

[2] E. Von Schweidler,

[3] W. F. G. Swann, *Phys. Rev.*, Vol. 9, pp. 555–557, 1917.

by the cosmic radiation which has passed through, so that the charging effect would depend upon the coefficient of absorption of the cosmic radiation itself. Much attention has recently been given to the question of the absorption of the cosmic radiation so that it is of particular interest at this time to consider again the possibilities as regards the charging effects of the type cited.

The earlier work led definitely to the conclusion that the absolute magnitude of the current absorbed by a solid copper cylinder 20.6 cm. in diameter, and 19.3 cm. high, is no more than 1.5 per cent. of that which would have been obtained by the complete absorption of a vertical corpuscular density sufficient to account for the replenishment of the earth's charge. Such small charging effects as were shown by the averages of the data indicated, if anything, a slight positive charging rather than a negative one, although no weight was placed on this conclusion. The earlier work was carried on in Norway and the limitations of time available at the stations prevented the attainment of as high a degree of sensitivity as it was felt should be practicable under ordinary laboratory conditions. The investigation now reported has still further depressed the limit represented by the above 1.5 per cent. down to 0.25 per cent.

The apparatus was set up on the top floor of the Physics Building at Cornell University so that in view of the fact that there was relatively small amount of material between the apparatus and the sky, the absorption of the cosmic radiation was not fundamentally serious. The method employed was in its essentials the same as that described in the earlier investigation, with one or two modifications calculated to increase the precision. It will therefore be sufficient to omit the description of most of the details and refer simply to the general outline of the procedure.

A and *B* represent two hollow copper cans which are insulated, connected together, and to the insulated portion of an electrometer. Surrounding these cans are two others *D* and *E*. A potential difference of the order of 120 volts was applied between the ends of a 100,000 ohm resistance. The center of this resistance was connected to the electrometer case and its ends to the cans *D* and *E* respectively. By this procedure any

fluctuations of the potential of the battery during the measurements may be compensated as regards their influence on the insulated system. Moreover, the ionization current in the air between the vessel A and D was compensated by the ionization current in the air between B and E. After taking readings of any residual current through the electrometer with the cans A and B empty, A was filled with the solid cylinder of copper, and the observations were repeated. The difference of course, gave the current produced by the absorption of the corpuscular radiation.

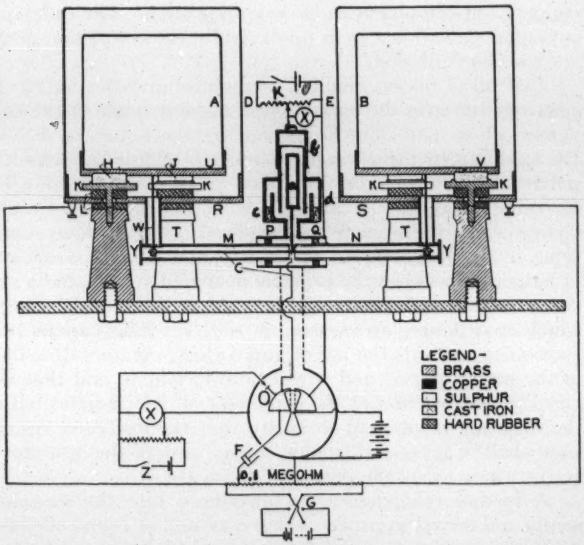
Instead of taking readings of the rate of deflection of the electrometer as in the earlier work, use was made of the condenser whose parts are designated by the letters a, b, c, d. By applying to the external member b of this condenser, a potential which could be varied and measured, it was possible to compensate the electrometer deflection produced by any charge which the system had acquired. Under these conditions, if V is the potential applied to b, and q_{12} is the coefficient of induction between the primary insulated system and b and the parts in conduction communication with it, the charge which it is desired to measure is $-q_{12}V$. The various precautions as regards the use of guard rings, etc., are described in the earlier paper, and it will be sufficient to add that the peculiar construction of the condenser, a, b, c, d indicated in the diagram, is adopted to insure that the insulated system itself shall be protected from a "direct view of the insulator d across which exists the potential difference V."

A further refinement was introduced into the measurements and served a purpose which may well be found effective in all measurements of this kind where a high degree of precision is necessitated. While the system of compensation already described provides a tremendously powerful guard against fluctuations of battery potentials, etc., its reliability depends upon the constancy of the ratio of the two sections of the 100,000 ohm resistance and it is not always easy to guarantee this constancy when one has to work, under conditions of very high humidity such as were encountered at Ithaca during the past summer, conditions in which it is customary to assume that an electrometer cannot be used at all.

The refinement in question consists of the following: The

electrometer needle was excited by a separate battery as shown in the present Fig. 1, instead of tapping off from the 100,000 volt resistance. The potentials were first applied to the outer cylinders so that the ions between the inner and outer cylinders were cleared out and a steady condition was

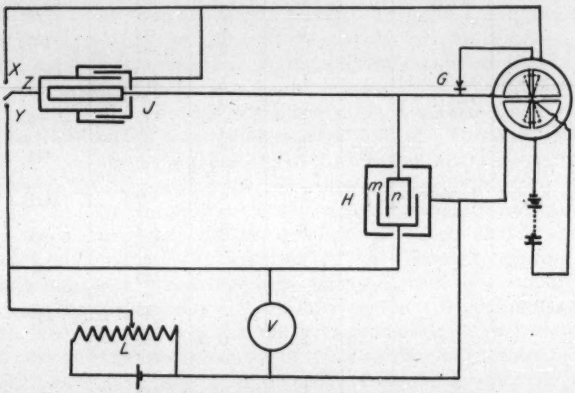
FIG. 1.



obtained. The potentials were then removed by raising the main battery switch. The key of the electrometer was raised and the reading θ_0 was observed. The potentials were then thrown on. If the balance was not perfect, there was a deflection. This deflection was approximately compensated by the potentiameter system K, and was kept compensated for the period of time (20 min. or so), during which the observation was in progress. The only purpose of this procedure was to keep the electrometer quadrant so near in potential to the case that leakage was inappreciable. At the end of the run,

the potentials were once more removed from the cylinders and the potentiameter was adjusted until the reading of the electrometer came to the value θ_0. The interval of time between the two observations of the reading θ_0 was the interval appropriate for use in the calculations. All effects of fluctuations of the battery or of the resistances were eliminated since the potentials were off when the first observations and the final adjustment to θ_0 were made. In other words, all inductive perturbations which may have taken place during

FIG. 2.



the run were cancelled when the potentials were removed, and the quantity recorded by the potentiameter measurement was a true representative of the quantity of electricity which had entered the system during the measured interval.

The quantity q_{12} was measured by the arrangement indicated in the diagram, Fig. 2. H is a Harms condenser whose coefficient of induction Q_{12} between its members m and n can be adjusted to known values indicated by its scale. J is the condenser indicated by a, b, c, d, in Fig. 1. The key k is first turned so as to connect Z to X, and with the electrometer quadrant connected to the electrometer case, a potential U_1 is applied to m. This induces on the conductor n and its

TABLE I.

Date and Time of Starting.	Remarks.	Group.	Disposition of Cylinder.	Zero Change Per Cent.	$\frac{dQ}{dt}$ e.s.u./sec. $\times 10^7$.	Mean $\frac{dQ}{dt}$ e.s.u./sec. $\times 10^7$.
Aug. 5, 1928 11:30 A.M.	Cloudy humid	1	L	6	287	285
				9	283	
			E	3	266	266
			R	0	176	176
Aug. 6, 1928 2:40 P.M.	Very humid had been raining	2	R	3	209	180
				5	151	
			E	12	263	259
				16	255	
			L	8	343	324
				2	304	
Aug. 7, 1928 10:00 A.M.	Very humid sun out and hot	3	L	3	279	304
				3	328	
			E	7	243	270
				4	296	
			R	18	229	223
				12	216	
Aug. 8, 1928 9:20 A.M.	Humid and sunny	4	L	1	309	321
				0	332	
			E	13	255	263
				7	270	
			R	8	271	257
				3	243	
2:30 P.M.		5	R	3	243	246
				9	248	
			E	6	222	
				14	235	246
				14	282	
			L	3	315	285
				12	255	
9:50 P.M.	Very humid sky overcast	6	L	49	226	268
				19	310	
			E	7	291	238
				32	185	
			R	23	155	210
				10	265	
Aug. 9, 1928 10:15 A.M.	Sun out humid	7	R	48	279	238
				15	173	
				17	263	
			E	4	271	259
				3	260	
				7	245	
			L	3	318	337
				6	351	
				4	342	

connection a charge equal to $Q_{12}U_1$. The electrometer key is now raised, Z is connected to Y and the electrometer deflection which results is reduced to zero by suitably adjusting the potential recorded by V to a value U_2. Under these conditions the total charge of the insulated system of which m is a part is equal to $(Q_{12} + q_{12})U_2$. Thus,

$$Q_{12}U_1 = (Q_{12} + q_{12})U_2,$$

which serves to determine q_{12} in terms of known quantities. In this manner the value 5.88 was obtained for the quantity q_{12}.

The Results. The method of tabulating results is similar to that adopted in the former paper. In Table I, the column dQ/dt represents the apparent corpuscular current obtained in the various experiments. L refers to the condition where the solid copper cylinder was in the left hand cylinder, R to the condition where it was in the right hand cylinder, and E the condition where the cylinders were empty. The only thing which can affect the reliability of the measurements is an actual change in the zero of the electrometer during the measurements. For this reason the differences between the readings of the electrometer with the quadrant key down at the beginning and end of the experiment, are recorded, expressed, however, as a percentage uncertainty in the whole apparent quantity of electricity collected during the corresponding run, the assumption being that the error produced, for example, by a change of x mm. in the zero of the electrometer is comparable with an uncertainty in the quantity of electricity necessary to produce a deflection of x mm. when the electrometer key is raised.

TABLE II.

E $\frac{\text{e.s.u.}}{\text{sec.}} \times 10^7$.	$R-E$ $\frac{\text{e.s.u.}}{\text{sec.}} \times 10^7$.	$L-E$ $\frac{\text{e.s.u.}}{\text{sec.}} \times 10^7$.	$\frac{R+L-2E}{2}$ $\frac{\text{e.s.u.}}{\text{sec.}} \times 10^7$.	i $\frac{\text{e.s.u.}}{\text{sec.}} \times 10^7$.
−266.0	90.0	−19.0	35.5	
−259.0	79.0	−64.5	7.3	
−269.5	47.0	−34.0	6.5	
−262.5	5.5	−58.0	−26.3	−3.7
−246.3	.8	−38.7	−19.0	
−238.0	28.0	−30.0	− 1.0	
−258.7	20.4	−78.3	−29.0	

The results are summarized in Table II, which corresponds to Table 2, in the former paper. The column labelled $\frac{R+L-2E}{2}$ gives the measured corpuscular currents for the individual sets of experiments, and the resulting mean is given in the column headed i. Only two of the individual measurements recorded under the next to the last column exceed the *mean* of all the measurements recorded in the former paper, and, the mean of means recorded in the present experiments, namely, -3.7×10^{-7} e.s.u. per second, is only about one-seventh of the corresponding quantity formerly recorded, so that taking into account the area of the top of a copper cylinder, and the magnitude -5.5×10^{-7} e.s.u. per sq. cm. second, as the atmospheric electric current density, the experiment indicates that the absolute magnitude of the current absorbed by a solid copper cylinder 20.6 cm. in diameter and 19.3 cm. high is no more than 0.25 per cent. of that which would have been obtained by the complete absorption of a vertical corpuscular current density sufficient to account for the replenishment of the earth's charge.

BARTOL RESEARCH FOUNDATION.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

IDENTIFICATION OF TYPEWRITERS AND GUNS BY PRECISION METHODS OF COMPARISON AND MEASUREMENT.

THE following paper was presented by Wilmer Souder of the Bureau of Standards at the Twenty-Second National Conference on Weights and Measures on June 5, 1929:

Identifications by comparisons have been made with more or less success for centuries. The application of precision measurement methods for these purposes is of recent origin and is not generally understood. This lack of understanding of the principles upon which the science is based is responsible for the confusion so often resulting from evidence introduced in courts of law.

We are so accustomed to the usual methods of description, which are only approximate and by virtue of these approximations are susceptible of no precise interpretations, that we fail to recognize the extreme accuracy of identifications made by precision measurements.

When we say we are looking for a man six feet tall of rather heavy build, with dark hair, with a scar on one hand and with some gold teeth in his mouth we should not be surprised to find several hundred citizens of the United States who meet the description. If we increase the precision of the description to a man 72½ inches tall, weighing 207 pounds, index finger of left hand amputated at the second joint and with gold crowns on left cuspid and right bicuspids, we may feel sure there is not more than one man in the entire country who will meet the specifications, and having found this one, further search cannot be justified without the introduction of some unusual condition.

The justification for this definite conclusion of positive identification is based on the "Law of Probability." Briefly and in non-technical terms this law is interpreted from the fraction which represents the ratio of the number of times a

* Communicated by the Director.

specific characteristic appears divided by the maximum number of appearances possible, and for two or more characteristics appearing simultaneously the probability ratio is represented by the product of the individual fractions.

The bureau has taken up the problems of identification of typewritten documents, guns, bullets, etc., in an effort to establish standards for this class of work. The bureau's interest is purely scientific and it is not prepared to handle cases in court.

There are now available a few experts who make identifications in a logical and precise manner but there are many so-called experts who recognize no limitations, no standards, and no equipment as essential in this field.

The instruments which are now generally recognized as essential for satisfactory work in these fields are the results of years of effort on the part of men who have been actively engaged in this work, and who have recognized the value of increased precision in making comparisons of data available for identifications.

In each instance the positiveness of identification increases with the increase in number of agreeing characteristics, the narrower limits of measurement, and the increase in precision of measurements. When, if ever, these ideal conditions are established there will be fewer conflicting expert opinions.

Precision measurements are the primary standards for identifications of questioned documents. The typewritten page may, at first glance, appear to be a perfect piece of work and not susceptible to an analysis of numerous individual characteristics which will prove it to be, beyond question of doubt, the product of one and only one certain machine. Type styles and characteristics distinguish one make of machine from another. Manufacturers using similar styles of type usually differ in dimensional proportions of the individual letters. For example, the i is given the same space as the w in the typewritten document, and it is the problem of the artist to design these and other letters in such manner as to minimize what could easily appear to be excessive crowding or isolation of type in the printed work. The modification of letters to avoid these defects gives the first opportunity for precision measurements.

For type made from the same model, or formed against the same die, we may look for defects or lack of all details of perfection over the lines of the letter face. The process of plating and polishing may add defects. The more sure source for identification, however, lies in the adjustments of the type on the bars after the machine has been completely assembled. Some letters will be placed high and some low in the line, some will be rotated and some will make contact on one portion of the face before the other portion hits the paper. Adjustments for minimizing these discrepancies are made by inspectors who usually reduce these to apparent uniformity insofar as the unaided eye is able to judge.

These variations are all susceptible to precision measurements and when these are made and compared with measurements from other machines it will usually be found that five to ten characteristics are sufficient to establish the identity of the machine which produced the document. The product of probability fractions rapidly reduces the probability of two machines existing which will produce documents having the characteristics specified. For the number of agreements given above and in the absence of unexplained disagreement the ratio usually reduces below the ratio for the number of machines in existence and therefore justifies the conclusion of identity.

The excellence of this type of evidence arises from the consistency of the variations; the evidence speaks from every line of the document and barring a few readily explainable variations there are no contradictions. Attempts at destroying these "beacon lights of evidence" through mutilation are seldom successful as to do so would require a perfect analysis of all defects in the machine and facilities for this type of analysis are limited.

Some of the special types of instruments used for comparing typewritten documents are shown in the accompanying illustrations (lantern slides were used at this point in the address). These are designs suggested and used by Albert S. Osborne, New York City examiner in questioned documents. Here, as in all fields of metrology, the value of the measurement depends upon the precision of the instrument and the ability of the user. Inaccuracies in either render the

results of little value. Experts in this field usually design their own types of measuring instruments and assemble numerous specimens of typewriting from which they draw conclusions as to what constitutes proof of identity.

Ballistic identifications have for their purpose the answer to the question: from what gun was a certain bullet fired? There is often a further question of identifying a case or shell as having been fired in the same gun. Evidence from measurements of guns, bullets, and shells have at present, in many instances, relatively little weight in courts of law except in their general confusion of juries, and the development of "a reasonable doubt." This is, to a large measure, because of the amateurish and incomplete methods pursued by many so-called experts. Properly prepared data on guns and bullets are often unique in the conclusiveness of identifications and often possess definite superiority over what is classed as direct visual evidence.

The points of superiority consist of the following:

(*a*) The markings are definite and can not display false or perjured statements.

(*b*) There is no limit to the time available for studying the case.

(*c*) The mental state of the observer need not be confused as is so often the case in visual observations of murders, etc.

(*d*) The findings are available to all parties interested and wishing to verify the conclusions.

The make of a gun is sometimes available from the gross markings on the bullet. Measurements of the land and groove widths, and depths, diameters and twist markings of the barrel give data for the identification of make of gun. Further progress must be made from the characteristic markings which arise from imperfections in manufacture of barrel or breech-mechanism. Rifling cutters do not have smooth edges. These tools wear with each cut, and the small saw tooth-like projections along the cutting edge produce a constantly changing pattern in the barrel. Bullets pressed against this surface will take these markings and retain them to a remarkable degree even after the penetration of many relatively hard materials. Rust spots and injuries to the inner surface of the barrel provide additional marks of

identification. Firing pin and breech markings on shells are equally positive when the shells are available for comparison.

Briefly the method of identification consists in comparing these characteristic markings on the questioned bullet or shell with the markings on a test bullet or shell fired through the gun in test. These tests are most satisfactory when made through a comparison microscope of the type perfected by the late Chas. E. Waite and by Col. Calvin Goddard of New York City. Images of the questioned and test bullets, or shells, from two microscopes each focused on a bullet or shell, are combined in a single eyepiece. These images may be caused to make contact with each other at corresponding positions over the surfaces being examined.

Usually there will be a few lines on one surface which do not have their counterparts on the other. These correspond to fouling marks, pieces of metal or powder, rust cavities, etc., which have developed between the two shots in question. Experience shows these to be not contradictory but properly regarded as further proof of the constant changes taking place with use. Incidentally these accidental changes should not be expected to render two guns more nearly uniform but rather, by virtue of their promiscuity, to render them more divergent and individualistic in their markings. The identity is established through the agreement of the numerous fine markings present, the agreement of all major markings and the absence of disagreements beyond those which may be ignored from the conditions mentioned above.

Bullets deformed by impacts with bones or other substances require special study as the dimensions of markings can not be expected to agree precisely with dimensions taken from the gun or from undistorted test bullets.

Skill in this field requires ability in the use of the microscope and in the ability to make precision measurements of diameter, angle and width of markings. Visual and photographic evidence must be complete and readily understood if it is to be of value in evidence.

Eventually it is predicted that this method of identification will be standardized and will furnish one of our most reliable means of identification.

The bureau plans to issue a publication on this subject, but it will not be available until some time in 1930.

INVESTIGATION OF LOSSES FROM LIGHTNING.

IN 1924 the Western Actuarial Bureau instituted an investigation among electric light and power companies in the territory west of the Alleghany Mountains reaching to the Pacific Coast and extending from Canada to the Gulf of Mexico. Arrangements were made with 248 companies in this territory to supply data regarding the value of the property exposed and the nature and financial extent of the damages caused by direct strokes of lightning or by surges occurring on their lines during lightning storms. The data secured covered principally the calendar years 1925 and 1926. Two hundred and forty companies scattered over 30 states sent in data. One hundred and sixty-five of these companies covered a period of at least two years. The only state in the specified area from which losses were not reported was Utah.

The total value of the properties exposed to damage by lightning, of the companies reporting, amounted to about $819,756,000. This value includes power houses and substation buildings, contents, and outdoor apparatus. The total losses attributed to lightning over a 2-year period amounted to slightly more than $631,000, or about 0.04 per cent. per annum.

The results of this survey have recently been analyzed by engineers of the Bureau of Standards and some interesting data have been secured regarding the detailed damage to the electrical apparatus. The table below will give some idea of the distribution of damage among different classes of equipment within stations and upon the overhead lines. Without counting interruptions to service due to circuit-breakers being tripped or fuses blown, and without counting instances of additional damage to fuses, there were reported altogether 4,450 instances of damage, and in 4,099 of these cases protection has been provided in the form of lightning arresters of one type or another. In presenting the results, nothing is said about the types of arresters involved, since the total number of arresters of each type is not known and consequently the number of cases of damage involving each type of arrester would not serve to discriminate as to the relative protective value of the different types. Neither has any attempt been made to indicate the value of arresters in

general, since without knowledge of the amount of protection provided, calculations cannot be drawn as to the extent to which protection was actually afforded. It is, of course, impossible to determine how much damage would have resulted if arresters had not been used at all.

Number of Pieces of Apparatus Damaged.	Total.	Having Arrester Protection.
Transformers, including 296 bushings	1,774	1,610
Metering equipment	1,280	1,250
Lightning arresters	137	——
Rotating machines	117	110
Oil switches, including 30 bushings	146	133
Air-break switches	71	61
Switchboards	13	13
Bus structures or insulators	35	34
Potheads	5	5
Line insulators	408	371
Line conductors	241	215
Pole or crossarm	215	155

It is to be noted that during the period in which 1,774 cases of damage to transformers occurred, there were 137 cases of damage to lightning arresters, or one case of injury to the arrester for every 13 injuries to transformers. While there is not a complete record of the voltage of each line upon which damage occurred, it may be said that most of the damages here tabulated occurred upon lines of low or medium voltage.

As an indication of the relative prevalence of lightning damage in the different states, data were selected where companies had reported the mileage of line exposed. The product of the number of miles of primary line and the number of lightning seasons involved in the records was divided into the number of instances of lightning damage upon those lines. The quotient thus obtained may be regarded as a coefficient showing the frequency with which lightning damage has occurred per mile per season. The values of this coefficient are given in the following table:

State.	Coefficient of Frequency of Lightning Damage.
Idaho	0.00055
California	.0062
Arizona	.012
Ohio	.013
Indiana	.023
Colorado	.026
Kansas	.026
Iowa	.032
Illinois	.033
Kentucky	.039
Arkansas	.072

Not all of the companies reporting gave data in a form to be used in this computation, and in some of the states there were not enough data to warrant making a computation for that state. The results in this table are based upon too few data to be highly reliable, but it is to be noted that states in the zone of most numerous lightning storms have the higher coefficients, while those far west show lower values.

The data collected disclose other items of interest. The frequency at which various companies are operating included the values of 20, 25, 30, 33, 50, and 60 cycles per second, although more than 96 per cent. of the companies were using the latter value. While the voltages most commonly reported were those known to be in general use, such as 2,300, 6,600, 11,000, 13,200, 22,000, 33,000, 60,000, and 66,000, there were altogether 74 values of voltage reported running all the way from 60 volts to 125,000 volts. This indicates that the selection of operating voltages is in this country far from being standardized. More than 70 per cent. of the lines reported, however, were operating at some one of the voltages above enumerated.

About 80 per cent. of the lines involved in this survey were reported as being provided with lightning arresters and about 20 per cent. as lacking such protection.

SAFEGUARDING STORAGE OF FILMS.

IN connection with the firemen's short course given at the University of Illinois, a paper was presented on June 18 by C. R. Brown of the Bureau of Standards on "Safeguarding the Storage of Photographic, X-Ray, and Motion Picture Films."

The recent disaster in Cleveland has emphasized the importance of proper storage of such films, large accumulations of which are often present in hospital buildings.

Most of the film used for the purpose up to the present has been of the nitrocellulose type that ignites at relatively low temperature, burns very rapidly, and gives off poisonous and flamable gases.

The storage of such film should be made in vaults constructed to resist moderate pressure from the rapid combustion of the film and mild explosions which sometimes accompany the fire. Suitable vents should be provided to the outside of the building for the gases given off. Self-closing doors, preferably opening inward into the vault should be provided, with sufficient strength to resist the pressure.

The arrangement within the vault should be such as to minimize the possibility of ignition of the film and at the same time afford easy extinguishment of fire by means of the automatic sprinkler protection required for such storage.

TESTING LATHE TOOLS WITH SHALLOW CUTS AT HIGH SPEEDS.

The bureau has developed a method for testing lathe tools under shallow cuts and fine feeds. It is based upon the fact that when two tools are set at equal depths in one tool holder the second or "trailing" tool will not cut until the "leader" or cutting tool begins to wear. With the carbon and high speed steel tools used, the second tool began to cut when the leader had worn 0.001 to 0.002 inch, and at this point the leader or test tool was considered to have failed. All subsequent comments on turning with shallow cuts and fine feeds are based on this end point, but greater wear can be made to represent tool failure by using a shallower setting for the second tool than for the cutting tool.

Tests were made dry at different cutting speeds, feeds, and depths of cut on nickel steel forgings with tensile strengths of 80,000 to 100,000 lbs./in.^{2} to give a broad background for the interpretation of the results of tests of different tool steels, first heat treated in various ways. The results could be respresented approximately by the following equations in which V is the cutting speed, T the tool life, F is the feed, D,

the depth of cut, A is the area of cut ($= DF$), c, K, K_1, K_2, and n are constants.

For high speed steel tools

$$VT^{1/10} = c, \tag{1}$$

$$V = K_1 - K_2(DF) = K_1 - K_2A. \tag{2}$$

For carbon steel tools

$$V = \frac{K}{DF} = \frac{K}{A}. \tag{3}$$

These equations are not to be construed to represent the true laws of cutting, since the cutting speed is probably not affected equally by variations in the feed and the depth of cut. However, they represent approximately the results of the experiments made with depths of cut of 0.005 to 0.020 inch and feeds of 0.0115 to 0.0204 inch per revolution.

In tests of short duration, where tool failure occurred in about 2 to 10 minutes, the tool life was increased somewhat more by the use of water than by lard oil, but in tests of about 50 minutes duration, under the same feed and depth of cut but lower cutting speeds, these two liquids produced effects of the same magnitude. The increases in tool life from the use of these liquids were not large in any case, but the finish on the work piece at the end of the cut was better with the liquids than without.

Tests with tools of different forms and angles showed that the successful application of the described method of test was not dependent upon having the broad nose tool used in a majority of the experiments. Tools with a plane angle of 65° had a longer life than the broad nose tools, but the finish produced on the nickel steels in dry turning did not appear to be as good. The best tool life with the broad nose tools was obtained with a back slope of 30°; a side slope of 0° was better than 8°.

The cutting speed of quenched carbon steel tools was not affected appreciably by variations in carbon content from 0.75 to 1.3 per cent. nor by subsequent tempering at temperatures up to 375° F. which did not lower the hardness; the

cutting speed of the carbon steel tools was equal approximately to that of a quenched "oil hardening" tool steel and only slightly lower than the cutting speed of a steel containing 1.3 per cent. carbon and 2.75 per cent. tungsten.

The cutting speed of carbon steel tools was lower in all cases than that of high speed steel tools but the differences between the two decreased with decrease in the areas of cut in dry turning.

The heat treatments which resulted in the best roughing tool performance for high speed steels of customary compositions also resulted in superior performance under shallow cuts and fine feeds. These treatments comprised oil quenching from the highest practical temperatures, followed by tempering to convert the larger part of the retained austenite to martensite.

Of 12 elements added in different proportions to chromium-tungsten or chromium-tungsten-vanadium high speed steels only one, cobalt, produced decidedly beneficial results. Molybdenum and nickel offered promise under certain conditions, while the remainder either had a negligible effect or were definitely deleterious from one viewpoint or another.

Cobalt improved the performance of the high speed steel tools both under shallow cuts and under heavy duty, but the maximum benefits were obtained only with high hardening temperatures. The percentage gain from the addition of cobalt was somewhat greater in rough turning than with shallow cuts and fine feeds, but increase in cobalt above about 5 per cent. did not produce improvements commensurate with those resulting from 3.5 to 5 per cent. plus high hardening temperatures.

Replacement of part or all of the tungsten in high speed steels by molybdenum, in the ratio of 1 part molybdenum to 2½ parts of tungsten, produced steels having performance comparable to that of the tungsten steels. Such substitution should be useful in case of a depleted tungsten supply, but is not advocated at the present time since there was some evidence of irregular performance in the high molybdenum steels and their hot working properties did not seem to be as good as those of the tungsten steels. However, a steel with 7 per cent. molybdenum and no tungsten had one advantage

over the tungsten steels for roughing tools in that its hardness and performance were not so largely affected by variations in the hardening temperatures.

The addition of 3.75 per cent. of nickel to the customary chromium-tungsten-vanadium steels was beneficial for the rough turning tools, particularly when combined with a 50° F. increase in the hardening temperatures, but was detrimental to the tools used under shallow cuts and fine feeds, and adversely affected the machining properties of the high-speed steel itself. Lowering the carbon from 0.6 or 0.7 per cent. to 0.5 per cent. improved the machining properties without affecting the performance of the roughing tools, but was detrimental to the tools used under shallow cuts.

Each of the four elements, arsenic, antimony, copper, and tin adversely affected the tool performance of high speed steels under shallow cuts, the magnitude of the decrease becoming greater as the proportions of these elements increased. Copper was the least harmful; next in order came tin, while arsenic and antimony were the most objectionable.

The effects of these four elements upon the performance of roughing tools did not necessarily correspond to those observed with shallow cuts. The 0.8 per cent. arsenic addition lowered the cutting speed. The addition of 0.4 per cent. antimony or 0.5 per cent. or less of tin had no measurable effect. Higher proportions of tin lowered the cutting speeds. The high speed steels containing 0.36 to 1.77 per cent. copper showed slightly better performance than the corresponding steels without copper.

The steels containing 0.4 per cent. antimony, 0.8 per cent. or more of copper, or 0.8 per cent. arsenic did not have good hot-working properties, illustrated by numerous corner cracks on the bars, while those containing 1.7 per cent. antimony or 1.8 per cent. tin showed a high degree of hot shortness and could not be forged or rolled. Also the steel with 1.77 per cent. copper could itself be machined only with difficulty in the annealed condition.

Phosphorus up to about 0.06 per cent. and sulphur up to 0.215 per cent. did not appear to be injurious, from the viewpoint of lathe tool performance of the customary chromium-tungsten-vanadium steels, with or without cobalt.

However, high sulphur tended to lower the cutting speeds in the presence of 3.75 per cent. nickel. Because of the possibility of segregation of the phosphorus and the introduction of numerous sulphide inclusions in high sulphur steels, these two elements can advisedly be kept within low limits for all high speed steel lathe tools.

Aluminum adversely affected the performance of the high speed steel tools both with shallow cuts and under heavy duty. It was one of the few metals considered which, in proportions around 0.3 per cent. produced a measurable decrease in the cutting speeds in rough turning. This decrease became greater as the proportion of the aluminum was increased, and with 0.8 per cent. the drop in cutting speed was greater than that produced by equal proportions of any of the other elements considered. These changes were accompanied by decrease in the hardness of the quenched steels probably through decrease in the dissolving capacity of the aluminum for carbon, chromium, tungsten, vanadium, and iron in solid solution. With 0.8 per cent. aluminum there was also evidence of a low melting eutectic in samples quenched from 2,350° F.

Titanium was another of the elements which appeared to lower the dissolving capacity of the austenite and as a result the hardness and the cutting speeds of the high speed steel tools decreased with increase in the titanium. Its interference was lessened, probably through the formation of less harmful carbides, instead of solution as titanium in the austenite, by increasing the carbon content of the steel.

Tantalum did not appear to be promising as a substitute for vanadium or as an alloying element in the customary chromium-tungsten high speed steels for lathe tools. It acted in a manner similar to aluminum and titanium in that it appeared to decrease the dissolving power of the austenite for the chromium and tungsten compounds and in this manner decreased the hardness and cutting speeds of the quenched lathe tools.

The complete report of this work will be published in the near future in the *Bureau of Standards Journal of Research.*

FREEZING TESTS ON SAND-LIME BRICK.

SOME preliminary experiments have been made to determine the best procedure for conducting a series of freezing tests on sand-lime brick.

Twenty-four brick of a single manufacture were used. They were divided into four groups, each group representing as nearly as possible an equal range of absorptions, as determined by a 72 hour cold, total-immersion test. All brick were given 10 cycles of freezing and thawing, the procedure being varied for each group. Bricks of Set 1 were frozen in ½ inch of water immediately after the 72 hour soaking. Bricks of Set 2 were frozen with no surrounding water, the first freezing starting directly after the 72 hour soaking. The other two sets were both cooled each time to 0° C. while totally immersed. Set 3 was then frozen in ½ inch of water, and Set 4 was frozen with no surrounding water. All brick were wiped with a damp cloth and weighed after each thawing. After the 10 cycles the brick were dried to constant weight in a gas-fired oven at 110° C. and reweighed.

It was found that the loss in weight of the bricks ranged from 0.3 to 2.8 per cent. of the original dry weight, and that as a rule the bricks with the higher water absorption had the lower percentage loss. The bricks of Set 2 showed a somewhat lower average percentage loss than the others, it being 1.0 per cent. The six bricks of Set 4 were next lowest with an average loss of 1.2 per cent. The others showed losses of 1.5 per cent.

The increase in water absorption was also calculated. It was found that the average increase in absorption for all the brick from the end of the 72 hours total immersion to the end of the 10 cycles was 2.8 per cent., the final absorption being calculated from the final dry weight. Set 1 had the largest increase, averaging 3.4 per cent., while Set 4 had the smallest, averaging 2.2 per cent. These results were obtained on only one make of brick and it would be unwise to draw any conclusions from them. Similar tests on a number of makes of brick are in progress.

SPECTRA OF CHLORINE, BROMINE, IODINE, KRYPTON, XENON, AND ARSENIC.

With the assistance of Dr. T. L. de Bruin, of the physics department of the University of Amsterdam and a research fellow of the International Education Board, the bureau has made remarkable progress during the past ten months in the description and interpretation of the spectra characterizing certain of the chemical elements which have not been thoroughly studied heretofore. These included the halogens, chlorine, bromine, and iodine; the heavy gases, krypton and xenon; and the metal, arsenic. The halogens usually give mixtures of several types of spectra, among which it is difficult to recognize that produced by the neutral atoms. The inert gases, krypton and xenon, exist in the earth's atmosphere, but only in very minute quantities, the former constituting but 0.00005 and the latter 0.000006 per cent. This is one of the principal reasons why their spectra have not been seriously studied since shortly after the discovery of these gases in 1898. Nothing of importance has been added to our knowledge of the arc spectrum of arsenic since an ultraviolet portion of it was first described in 1893.

Standard descriptions of these long neglected spectra have now been prepared by the bureau. In each case important extensions have been made to the infra-red portions which have been investigated photographically by special methods developed in the Bureau's laboratory, and it is in fact these observations which have given the clues to the spectra. The structure of the spectrum in each case is determined by the structure of the atom and the latter may be deduced from the former by identifying various states of atomic energy from certain relationships between the emitted lines.

The interpretation of any spectrum has been made possible in recent years by the advances in quantum theory, but in most cases the empirical data are still too incomplete or inaccurate to permit complete analysis. Many laboratories the world over are now engaged with these problems. Any one of them is proud if it finishes one spectrum a year. The Bureau of Standards with the services of Doctor de Bruin has established a record by defining and explaining no less than six different spectra in a period of ten months.

CONFERENCE ON AIRPLANE ENGINE IGNITION SHIELDING.

A CONFERENCE on airplane engine ignition shielding was held at the bureau on Tuesday, June 11, for the purpose of coördinating information available on the subject and stimulating the standardization of shielding practice. This was called and conducted by the bureau, in response to a number of requests. There were 57 persons present, representing the interested Government departments, airplane, airplane engine, magneto, spark plug, and cable manufacturers, as well as the manufacturers and research organizations interested in the use of radio on aircraft.

Talks were given by representatives of the various interests on their experience with ignition shielding and the points to be considered in an ideal installation. Some of the representatives displayed samples of their most recent development in this line, and the Bureau of Standards exhibited a complete shielding assembly showing its recent developments. Tentative specifications enumerating the various requirements for effective and safe ignition shielding were discussed. There was good agreement on the factors essential to proper radio shielding. The main discussions were centered around standardization of magneto shielding, spark plug shielding, and standard tests to determine efficiency of shielding.

A report of this conference is being prepared. Copy can be secured by anyone interested, on application to the Bureau of Standards, Washington, D. C.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

ON THE RELATION BETWEEN TIME AND INTENSITY IN PHOTOGRAPHIC EXPOSURE [1]

L. A. Jones and V. C. Hall.

THIS paper is a summary of results obtained the last six years in study of the failure of the so-called reciprocity law of Bunsen and Roscoe, $E = I \cdot t$, where E is the exposure or insolation and I and t are the intensity and time of exposure, respectively. The apparatus used was a time-scale rotating sector sensitometer with exposures made during a single revolution of the disk. Exposures can be made from 0.00012 second to 72 hours and the intensity varied from 0.00008 meter candle to 1280 meter candles, without variation of quality from the standard of 2500° K. Even longer exposures can be made in a special instrument designed for very long time-scale exposures. The results show that in the region of optimal intensity the behavior of the plate can be well represented by plotting log exposure against log intensity for a constant density and using the catenary equation

$$\log E = \log \frac{I_0 t_0}{2} \left[(I/I_0)^a + (I/I_0)^{-a} \right],$$

where I_0 and t_0 are the values of intensity and time at optimal intensity for the density in question. The curvature, or amount of departure from the reciprocity relation, is governed by a. For a normal emulsion a varies between 0.16 and 0.24 but usually is close to 0.20. This value is independent of the developer and practically independent of development time for any given density. Optimal intensity tends towards higher intensities for slower emulsions, higher densities, and longer development. The variation of density with log intensity for constant exposure shows an optimal

* Communicated by the Director.

[1] Communication No. 346 from the Kodak Research Laboratories and published in *Proc. Seventh International Congress Photography*, 115 (1929).

intensity also, while for low intensities on slow plates the density developable drops to a small fraction of that at optimal. From this and the fact that maximum developable density decreases at low intensities it is concluded that small insensitive grains become inert at low intensities.

SYSTEMATIC NOMENCLATURE IN PHOTOGRAPHIC SENSITOMETRY.[1]

L. A. Jones

THERE is a great need for the establishment of some systematic nomenclature in the field of photographic sensitometry. At the present time there are no recognized units in terms of which to express the quantities which are dealt with in this field of science. It is proposed to construct a systematic terminology and units analogous to those which have received international approval in the field of photometry and illumination. The terms proposed are built up by using the Greek word *phos* as a combining form with various attached endings. It is further proposed to name several of these units, following the precedent already established in other fields, after men of great prominence in a particular field of science. A summary of the proposed specific terms, name of unit, symbol, defining equation, and abbreviation for the unit names are shown in the following table.

Photic Quantity.	Name of Unit.	Symbol and Defining Equation.	Abbreviation for Name of Unit.
Radiant flux	Erg per second (Watt)	J	–
Photic flux	Photon	P	p
Photic intensity (Abney power)	Abney	$A = \frac{dP}{dW}$	a
Photivation	Hurter	$H = \frac{dP}{dS}$ (incident)	h
Photiveness	Daguerre	$G = \frac{dP}{dS}$ (emitted or reflected)	d
Exposure	Eder	$E = Ht$	e
Photibility		$M_\lambda = \frac{P_\lambda}{J_\lambda}$	–
Photocity		$Z_\lambda = J_\lambda \cdot M_\lambda$	–

[1] Communication No. 350 from the Kodak Research Laboratories and published in *Proc. Seventh International Congress Photography*, 265 (1929).

THE EXPRESSION OF PLATE SPEED IN TERMS OF MINIMUM USEFUL GRADIENTS.[3]

L. A. Jones and M. E. Russell.

THE expression of plate speeds in terms of reciprocal inertia values, the inertia being defined as the exposure value where the straight-line portion of the characteristic curve extended cuts the log E axis, is not in all cases entirely satisfactory. This is particularly true when the straight-line portions do not intersect at a point and when fog is excessive. It is common practice in many fields of photography to utilize a large portion of the under-exposure region. If a speed value is to be used for the computation of camera exposure, the inertia value is of little utility and effective speed should be expressed in terms of the exposure corresponding to the lowest useful density. From the standpoint of tone reproduction theory, it seems most logical to specify this lowest useful density in terms of the minimum useful gradient. To illustrate the relation between speed values expressed in terms of minimum useful gradient in comparison with those based on reciprocal inertias, a group of materials representing a wide range of speed and contrast were chosen. For each of these materials, a group of characteristic curves obtained from sensitometric strips developed to different extents are shown. An examination of the tabulated speed values shows that in case of high speed panchromatic materials the ratio between the two values is much greater than in case of low-speed high-contrast materials. It is suggested that where a speed value is desired for the computation of camera exposure, the minimum useful gradient method be adopted.

ON THE MEASUREMENT OF RESOLVING POWER OF PHOTOGRAPHIC MATERIALS.[4]

O. Sandvik.

THE first part of the paper is devoted to a brief résumé of the earlier investigations on resolving power of the photographic plate.

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[3] Communication No. 351 from the Kodak Research Laboratories and published in *Proc. Seventh International Congress of Photography* 130 (1929).

[4] Communication No. 352 from the Kodak Research Laboratories and published in *Proc. Seventh International Congress of Photography* 243 (1929).

The latter part contains a short account of more recent work on the same subject. A few curves with data are included to illustrate the variation of resolving power with the type of test object, the contrast in the test object, and the wave-length.

It is concluded that the resolving power is a complex function which cannot be readily arrived at from general definitions and cannot be evaluated in terms of a single factor characteristic of a particular emulsion.

It appears most desirable, therefore, to measure resolving power directly according to a prescribed set of conditions in order that one may be able, by referring to the literature, to find the emulsion best suited for a particular purpose.

The last part of the paper contains a brief outline of the experimental conditions which the author believes most desirable and it is recommended that these be adopted.

A HIGH INTENSITY TIME-SCALE SENSITOMETER[6]

L. A. Jones and G. A. Chambers.

IN the sensitometery of photographic materials it seems desirable to measure speed under conditions directly comparable with those existing in the camera as used in practice. The illumination incident on the photographic materials when being exposed in the camera is very much higher than that commonly used in sensitometry. It is well known that the reciprocity law is not valid, and hence the speed value obtained depends on the illumination level used in its measurement. An instrument has been designed giving exposure times ranging from 0.00025 second up to 0.512 second, with an illumination of thirty meter candles incident on the material during exposure. The exposure times required were obtained by two rotating sector wheels, one of which revolves at a speed of 600 r.p.m., and the other at a speed of 600/32 r.p.m. The slow moving sector wheel serves also as a selecting shutter so that one out of every thirty-two flashes given by the high speed sector is allowed to impinge on the

[6] Communication No. 353 from the Kodak Research Laboratories and published in *Proc. Seventh International Congress of Photography*, 206 (1929).

photographic material under test. The illumination is obtained by a small incandescent lamp mounted relatively close to the exposure plane. This is moved laterally one step for each revolution of the slow moving sector in such a way that each step on the material receives but a single flash, thus giving a non-intermittent exposure. The results obtained show appreciable differences in speed value obtained with this instrument and one having an illumination of 0.25 meter candle. In the case of high speed materials values obtained with the high intensity instrument are lower than those obtained on the low intensity instrument, while in the case of low speed materials the reverse is true. These results are in agreement with our knowledge of the reciprocity relationships for these materials.

INTENSIFICATION OF PHOTOGRAPHIC LATENT IMAGE. III.[4]

E. P. Wightman and R. F. Quirk.

THE results of previous work were reviewed, as well as the hypothesis which was offered to explain them. Additional facts have been obtained, and are presented, which lend further support to this hypothesis. These are:

(*a*) The latent image intensification is largely independent of the developer used.

(*b*) No latent image intensification is obtainable with X-ray exposures.

(*c*) Acetone-semicarbazone, a bromine absorber, apparently lessens or prevents intensification of latent image by hydrogen peroxide, but at the same time itself causes a latent image intensification.

Organic peroxides as well as hydrogen peroxide are capable of producing intensification of latent image.

In conclusion, it is considered that only those substances which act on the latent image specks can produce latent image intensification. It is further considered that those which act in general on the silver halide to form new specks do not produce latent image intensification but only fog.

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[4] Communication No. 355 from the Kodak Research Laboratories and published in *Proc. Seventh International Congress of Photography*, 235 (1929).

EFFECT OF ANILINE ON CELLULOSE TRIACETATE.[7]

H. LeB. Gray, T. F. Murray, Jr., and C. J. Staud.

CELLULOSE triacetate is saponified when heated with aniline without simultaneous hydrolysis to alcohol- or ether-soluble products. At 183° C., the acetyl content is reduced to 2.0 per cent. after one hundred hours of heating of 15 grams cellulose triacetate with 300 c.c. of aniline. Reacetylation of this product yields a compound containing 44.2 per cent. acetyl (theoretical cellulose triacetate 44.8 per cent., and having $(\alpha)^{25^\circ}_{546.1\ m\mu} = -26.5^\circ$ ($C = 1$ per cent., $1 = 2$ dm.) in chloroform-alcohol 85 : 15 per cent. by volume. Saponification was also conducted at 148–151° C. and a product containing 10.4 per cent. acetyl was obtained after 150 hours. Saponification curves are given at both temperatures and have an S-form in which splitting off of acetyl is slow at the start, more rapid during intermediate stages, and again slow at the lower values. Solubilities in various solvents during saponification are included. Aniline at 20–30° C. is shown to have a negligible effect on cellulose triacetate over a period of 150 hours.

[7] Communication No. 377 from the Kodak Research Laboratories and published in *J. Amer. Chem. Soc.*, **51**: 1810 (1929).

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LIBRARY NOTES.

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BOOK REVIEWS

X-RAYS IN INDUSTRY. Rochester. Eastman Kodak Company. 1929. 60 pages, illustrations, 8vo. Sent on request.

X-ray photography is connected in the public mind with certain phases of medical and dental practice. Such a valuable method would not readily confine itself to these uses in this day of alertness in finding new methods. X-rays are being used increasingly to determine the internal structure of opaque objects.

Steel castings, aluminum castings, metal radio transmission tubes, a variety of other metal objects, even trees and telegraph poles, have been subjected to X-ray examination. Such examinations have become regular practice in some factories. The principal work along these lines has been done in the Watertown Arsenal and the Massachusetts Institute of Technology in the United States, and in the Woolwich Arsenal in England.

Information on this subject as part of a survey of the theory and use of X-rays in industry, is included in this pamphlet. The publication has the intention of suggesting some of the industrial applications of X-rays in inspecting the internal construction of opaque materials.

L.

POLAR MOLECULES. By P. Debeye, Ph.D., Professor of Physics and Director of the Physical Institute in the University of Leipsig. 172 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1929. Price $3.50.

The word polarity now used so extensively in science is primarily connected with the idea of two distinct points or conditions which determine in some way the properties of a substance. It is extended however, to intangible things for the very familiar use of it is in the expression polarization of light. The present work which is of high mathematical character constitutes, as the preface says, the survey of questions treated in connection with the conception of polar molecules as being systems having a distribution of electrical charges which can be characterized by a permanent electric moment. The book is valuable on account of being a collection from a wide range of literature in many countries and many lands. To bring these all within a comparatively brief compass that the facts may be accessible to the American reader is a service of great merit for which the author deserves much praise. The book is interesting because it appears from the preface that it is written in English by a Professor from a German institution. He acknowledges assistance from American teachers but, nevertheless, he shows a very satisfactory acquaintance with the English language. It is also stated in the preface that he has been a visitor to this country. He has been a contributor for a considerable number of years in this field having begun publication in 1912 and he has seen the theories of the subject grow in volume and comprehensiveness in the intervening years. The book will appeal to those who are pursuing the higher mathematical phases of physical chemistry and constitutes one more striking evidence of how certain parts of chemistry are being absorbed into physics while the books on analytical procedures and industrial operations show the development of chemistry in an entirely different direction. How far these two phases may fall part in the future it is not possible to say but it is also impossible that any scientist could carry a complete knowledge of both.

HENRY LEFFMANN.

MECHANISM OF ENZYME ACTION AND ASSOCIATED CELL PHENOMENA. By F. F. Nord, Fellow, Physiological Institute, Tieraerztliche Hochschule, Berlin. 78 pages, illustrations, 8vo. Baltimore, The Williams & Wilkins Company, 1929, price $2.00.

That vast number of substances which promote chemical change without taking final part in it and which appear, therefore, at the end of the reaction in the same amount as at the beginning has been grouped under the titles of "catalysts" and "enzyms." The properties and methods of action of these substances have been studied closely for many years. Berzelius coined in 1836 the word "catalyst" which, of course, is merely a combination of two Greek words which might be translated to loosen up or down. It is interesting to note, however, that four years before this coinage, Döbereiner had published the interesting and puzzling fact that the decomposition of potassium chlorate was greatly promoted by a small amount of manganese dioxide and that the latter was so far unchanged that it could be used many times for the effect.

Up to the period within the memory of the older chemists scientists were ignorant of the relation of minute life to the transformation of organic materials. The action of manganese dioxide remained for a long while practically the only familiar instance of an inorganic catalyst. Modern industrial chemistry has developed the use of very many of this type. The subject of enzym action has probably been somewhat restricted in development by the lack of coöperation between the biologist and the chemist. The organic enzyms themselves are difficult to obtain in the pure form and they have some properties which suggest that they are intermediate between living and non-living matter. Modern investigation, which has been very extensive, has shown that in many cases, probably in all, the minute organism produces certain enzyms by which its nutrition is accomplished. The human being and the yeast cell have the common purpose and method in life, namely to get food and digest it so that it may be assimilated. The human being by means of the several digestive enzyms in the saliva, the gastric juices and other secretions of the digestive tract brings the proteins, fats and carbohydrates into nutritive forms; the humble yeast cell, invisible to the naked eye, also has its digestive forms by which it turns the sugars into alcohol and carbon dioxide thus building up its own structure in its own interest and producing incidently in the fermented liquid a substance which has given a problem to humanity since the morning twilight of civilization.

It is the purpose of this book to extend the orientation in certain sections of enzym chemistry. It is a summary of lectures delivered by the author in the United States and also in Japan and India. The English text is the work of the author and is a worthy exposition of his linguistic accomplishments. The subject is of intense interest and the work will be a valuable contribution to it.

HENRY LEFFMANN.

THE ELECTRICAL CONDUCTIVITY OF THE ATMOSPHERE AND ITS CAUSES. By Victor F. Hess, Ph.D., Professor of Experimental Physics in the University of Graz (Austria). Translated from the German by L. W. Codd, M.A. (oxon). xix–294 pages, 15 figures. New York, D. Van Nostrand Company, 1928. Price $4.

According to the author this book is the first general treatise on Atmospheric Ionization so far to appear in the English language. The material of this book

and its presentation is such that it is intended to fill the needs of an extensive group of readers who are both directly and indirectly interested in the electrical conductivity of the atmosphere. Introductory sections on the laws of gas ions, conductivity in gases and the fundamentals of radioactivity have been included for the benefit of the general reader.

Following a short introductory chapter the author discusses the conductivity of the atmosphere which includes a summary on the fundamental properties of gas ions; new and improved methods for counting these ions and a consideration of the theoretical principles and sources of error. In order to account for the presence of ions in the atmosphere attention must be paid to all the agencies which are possible ion sources. The two most important sources of ion production are the radioactive substances and the ultra-gamma rays, these latter being a strongly penetrative radiation from the outer spaces. From data already available a rather remarkable agreement may be obtained between the atmospheric ion content values calculated from the known concentration of ion-producing agencies and those values measured experimentally. The latter part of the book consists of a very interesting discussion on the electrical conductivity and ionization of the upper layers of the atmosphere. This region, often referred to as the Heaviside Layer, has commanded widespread attention since the advent of radio communication.

This book is to be recommended most highly particularly to those who wish to acquire general information concerning the electrical properties of the atmosphere. The author has presented his material in an engaging manner, thanks to the translator who has done his task extremely well.

T. K. CLEVELAND.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 307. The Pressure Distribution Over the Horizontal and Vertical Tail Surfaces of the F6C-4 Pursuit Airplane in Violent Maneuvers, by R. V. Rhode. 20 pages, illustrations, quarto. Washington, Government Printing Office, 1929. Price, ten cents.

This investigation of the pressure distribution on the tail surfaces of a pursuit airplane in violent maneuvers was conducted by the National Advisory Committee for Aeronautics at the request of the Navy Bureau of Aeronautics for the purpose of determining the maximum loads likely to be encountered on these surfaces in flight. The information is a part of that needed for a revision of existing loading specifications to bring these into closer agreement with actual flight conditions. A standard F6C-4 airplane was used and the pressure distribution over the right horizontal and complete vertical tail surfaces was recorded throughout violent meaneuvers. The results show that the existing loading specifications do not conform satisfactorily to the loadings existent in critical conditions, and in some cases were exceeded by the loads obtained.

An acceleration of 10.5 g was recorded in one maneuver in which the pilot suffered severely; it is therefore indicated that the limits of the physical resistance of the pilot to violent maneuvers are being approached.

Navy specifications for the structural design of tail surfaces are included as an appendix.

Report No. 313. Drag and Cooling with Various Forms of Cowling for a "Whirlwind" Radial Air-Cooled Engine—I, by Fred E. Weick. 26 pages, illustrations, quarto. Washington, Government Printing Office, 1929. Price, fifteen cents.

The Committee has undertaken an investigation in the Twenty-Foot Propeller Research Tunnel at Langley Field on the cowling of radial air-cooled engines. A portion of the investigation has been completed, in which several forms and degrees of cowling were tested on a Wright "Whirlwind" J-5 engine mounted in the nose of a cabin fuselage. The cowlings varied from the one extreme of an entirely exposed engine to the other in which the engine was entirely enclosed. Cooling tests were made and each cowling modified, if necessary, until the engine cooled approximately as satisfactorily as when it was entirely exposed. Drag tests were then made with each form of cowling, and the effect of the cowling on the propulsive efficiency determined with a metal propeller.

The propulsive efficiency was found to be practically the same with all forms of cowling. The drag of the cabin fuselage with uncowled engine was found to be more than three times as great as the drag of the fuselage with the engine removed and nose rounded. The conventional forms of cowling, in which at least the tops of the cylinder heads and valve gear are exposed, reduce the drag somewhat, but the cowling entirely covering the engine reduces it 2.6 times as much as the best conventional one. The decrease in drag due to the use of spinners proved to be almost negligible.

The use of the cowling completely covering the engine seems entirely practical as regards both cooling and maintenance under service conditions. It must be carefully designed, however, to cool properly. With cabin fuselages its use should result in a substantial increase in high speed over that obtained with present forms of cowling on engines similar in contour to the J-5.

Report No. 315. Aerodynamic Characteristics of Airfoils—VI, by National Advisory Committee for Aeronautics. 38 pages, illustrations, quarto. Washington, Government Printing Office, 1929. Price, twenty cents.

This collection of data on airfoils has been made from the published reports of a number of the leading aerodynamic laboratories of this country and Europe.* The information which was originally expressed according to the different customs of the several laboratories is here presented in a uniform series of charts and tables suitable for the use of designing engineers and for purposes of general reference.

It is a well-known fact that the results obtained in different laboratories, because of their individual methods of testing, are not strictly comparable even if proper scale corrections for size of model and speed of test are supplied. It is, therefore, unwise to compare too closely the coefficients of two wing sections tested in different laboratories. Tests of different wing sections from the same source, however, may be relied on to give true relative values.

The absolute system of coefficients has been used, since it is thought by the

* A previous collection of airfoil sections numbered 1 to 759 and Charts 1 to 20 may be found in N. A. C. A. Reports Nos. 93, 124, 182, 244, and 286.

National Advisory Committee for Aeronautics that this system is the one most suited for international use and yet it is one from which a desired transformation can be easily made. For this purpose a set of transformation constants is given.

Each airfoil section is given a reference number, and the test data are presented in the form of curves from which the coefficients can be read with sufficient accuracy for designing purposes. The dimensions of the profile of each section are given at various stations along the chord in per cent. of the chord length, the latter also serving as the datum line. The shape of the section is also shown with reasonable accuracy in order to enable one to more clearly visualize the section under consideration, the outside of the heavy line representing the profile.

The authority for the results here presented is given as the name of the laboratory at which the experiments were conducted, as explained under abbreviations, with the size of model, wind velocity, and year of test.

Report No. 316. Tables for Pressure of Air on Coming to Rest from Various Speeds, by A. F. Zahm and F. A. Louden. 8 pages, quarto. Washington, Government Printing Office, 1929. Price, five cents.

In Technical Report No. 247 of the Committee theoretical formulas are given from which was computed a table for the pressure of air on coming to rest from various speeds, such as those of aircraft and propeller blades. In that report, the table gave incompressible and adiabatic stop pressures of air for even-speed intervals in miles per hour and for some even-speed intervals in knots per hour. Table II of the present report extends the above-mentioned table by including the stop pressures of air for even-speed intervals in miles per hour, feet per second, knots per hour, kilometers per hour, and meters per second. The pressure values in Table II are also more exact than the values given in the previous table.

To furnish the aeronautical engineer with ready numerical formulas for finding the pressure of air on coming to rest, Table I has been derived for the standard values specified below it. This table first presents the theoretical pressure-speed formulas and their working forms in C.G.S. units as given in N. A. C. A. Technical Report No. 247, then furnishes additional working formulas for several special units of speed. R.

PUBLICATIONS RECEIVED.

Mechanism of Enzyme Action and Associated Cell Phenomena, by F. F. Nord. 78 pages, illustrations, 8vo. Baltimore, The Williams and Wilkins Company, 1929.

Ondes et Électrons, par Pierre Bricout. Collection Armand Colin. 215 pages, illustrations. 16mo. Paris, Armand Colin, 1929, price nine francs.

Structure de l'Atome, Tourbillon d'Éther et Pensées Scientifiques Indépendentes par L. Cugnin. 184 pages, 8vo. Sceaux, Marcel Bry, 1929.

Professor Coker's *Photo-elastic Apparatus for Determining the Distribution of Stress in Structural and Machine Members.* 28 pages, illustrations, 8vo. London, Adam Hilger, Ltd., 1929.

Manual of Second and Third Order Triangulation and Traverse. Special Publication No. 145 U. S. Coast and Geodetic Survey. 226 pages, illustrations, plates, 8vo. Washington, Government Printing Office, 1929, price sixty cents.

National Advisory Committee for Aeronautics, Technical Notes: No. 307. Strength of Tubing and Combined Axial and Transverse Loading by L. B, Tuckerman, S. N. Petrenko and C. D. Johnson. 17 pages, illustrations, quarto. No. 308, Pressure Distribution on a Slotted R. A. F. 31 Airfoil in the Variable Density Wind Tunnel by Eastman N. Jacobs. 13 pages, illustrations, quarto. No. 309, Correcting Engine Tests for Humidity by Donald B. Brooks. 12 pages, illustrations, quarto. No. 310, Wind Tunnel Pressure Distribution Tests on a Series of Biplane Wing Models, Part 1, Effects of Changes in Stagger and Gap by Montgomery Knight and Richard W. Noyes. 13 pages, illustrations, quarto. Washington, Committee, 1929.

Bell Telephone Laboratories, Inc. Reprints: B323, Telephone Toll Plant in the Chicago Region by Burke Smith and G. B. West. 16 pages, illustrations, 8vo. B369, Lead-Tin-Cadmium as a Substitute for Lead-Tin Wiping Solder by Earle E. Schumacher and Edward J. Basch. 8 pages, illustrations, 8vo. B372, Some Contemporary Advances on Physics—XVII Scattering of Light with Change of Frequency by Karl K. Darrow. 30 pages, illustrations, 8vo. B396, Magnetic Alloys of Iron, Nickel and Cobalt by G. W. Elmen. 35 pages, illustrations, 8vo. New York, 1929.

CURRENT TOPICS.

The Mediterranean Fruit Fly. This has developed into a serious insect pest affecting particularly as its name indicates fruits grown in warmer regions of this country. A large amount of damage has already been done and, as in such cases, state lines constitute no barrier to the spread of the plague, the Federal Government has taken the matter in hand. The Department of Agriculture has just issued a summary of work so far done by its officers in tabulating the amount of damage that may be done by the insect and the means so far developed for its eradication. It is shown that a very large amount of money loss will result unless the insect is promptly checked in its spread. One of the most important problems in connection with this restriction is to secure the co-operation of the citizens of Florida, the state in which the infection now exists, and also a positive disciplinary control over transportation of fruit and management of orchards. Harm may easily be done by visitors to the state sending away samples of fruit, unaware of the infection by some stage of the life of the fly.

The preliminary report expresses a rather optimistic view inasmuch as the work of eradication has shown favorable results, but it is obvious that a large increase of the inspection force and considerable additional expenditure of money will be necessary before safety can be assured.

The invasion by this fly constitutes the fifth instance of the serious threat to agriculture from foreign sources and shows that our rapid interchange between the nations has its drawbacks. The Gypsy Moth, the Corn Borer, the Boll-Weevil, the Japanese Beetle and now this Mediterranean pest constitute a "quintessence" of problems that have cost millions of dollars to our agricultural interests. H. L.

The Effect of Substituting Ethylene Glycol Dinitrate in Permissible Explosives. G. St. J. Perrott and J. E. Tiffany, U. S. Bureau of Mines, Reports of Investigations, May, 1929. Comparisons between samples of permissible explosives in which 25 per cent. of the explosive oil had been replaced by 25 per cent. of ethylene glycol dinitrate and samples in which no change had been made show that the substitution does not have any marked effect on the

properties of the explosive. There are, however, certain well-marked tendencies which may be summarized as follows:

The substitution of ethylene glycol dinitrate tends (1) to increase the rate of detonation, (2) not to affect the unit deflective charge, (3) to increase slightly the sensitiveness by the halved cartridge method, (4) not to affect the limit charge to an extent that the samples containing ethylene glycol dinitrate should be considered any less safe for use in coal mines. H. L.

Some effects of Radiant Energy on Plants. J. M. ARTHUR. (*Jour. Opt. Soc. Am.*, March, 1929.) Here are reported experiments conducted at the Boyce Thompson Institute for Plant Research, Yonkers, N. Y. The natural conditions under which plants grow include wide variations in the quality, intensity and duration of solar radiation received. Plants show wide adaptability under shifting conditions. "One might even conclude that the plant will grow in about any quality and intensity of radiation. Only by exceeding the limits of intensity, quality and duration ranges of solar radiation can one be convinced that after all the plant is not only not indifferent to these changes but is attuned to some of them and is easily injured whenever the natural range is greatly exceeded in any direction. Any great increase in day length results in injury to some plants, and certainly any great extension of the range of wave-lengths included in the extreme ultra-violet component of the solar spectrum will result in injury."

Plants were grown under different glass filters. Those plants receiving the visible spectrum and the ultra-violet wave-lengths to 3130 Å. were about the same as those that grew with the visible spectrum and 80 per cent. of the incident radiation at 2900 Å. Plants grown under the visible spectrum from which the blue region had been absorbed had thin stems and small leaves. They looked as if grown in deep shade. "When plants are grown without the red they have a normal appearance but probably on account of the low intensity under this glass they do not grow to normal height. Further experiments are now in progress to determine whether by increasing the solar intensity under this filter a plant can be grown which has the same height and weight as under the complete solar spectrum of the same intensity." Pictures of the plants make clear that the absence of the blue from the incident radiation is much more deleterious than the absence of the red.

A study of the effect of duration of exposure to radiation was made. Sunlight was supplemented by gas-filled incandescent lamps. Carbon dioxide was supplied to the plants. "Some plants, such as the tomato, will not withstand continuous illumina-

tion. A leaf injury appears in about five days under continuous exposure and gradually increases until most of the leaves have withered and dropped off the plant." The effect of extra long days on a plant depends upon whether it flowers in long or short days of the year. "Plants such as lettuce and radish, which flower on the long days of summer, flower on day lengths greater than 12 hours." Lettuce for day lengths of less than 12 hours tends to form a head. "Short day plants which normally flower in the spring or fall flower on 15 hours or less exposure to artificial illumination." Pictures of a series of six salvia plants are given. These show flowers for exposures of 5, 7 and 12 hours per day while there are no flowers, but only large, sturdy growth on those exposed for 17, 19 and 24 hours a day. Nineteen hours produced the largest plant. Buckwheat, an "everblooming" type, produces flowers on all day lengths from 5 to 24 hours.

The effect of radiation from a mercury arc lamp in quartz was studied. "Plants were exposed at a distance of approximately 15 inches from the quartz tube to the tip of the plant, and through an opening 6 inches square in the metal shield around the lamp. When young tomato plants are exposed to the open arc as outlined above, severe injury and a killing back of a great part of the leaf area are produced in 30 secs. "By the use of a series of filters transmitting progressively shorter and shorter wave-lengths in the ultra-violet it became clear that the rate of injury increases rapidly with decrease of wave-length. Illumination through a filter transmitting a radiation shorter than 2700 Å. requires 12 hours to do as much damage as is wrought in one hour by what comes through a filter with its limit at 2370 Å. When there is no change of wave-length the injurious effect is in proportion to the rate at which energy falls on the plant. No marked stimulation, but only injury to the plant, has been discovered as the result of irradiation by ultra-violet light.

G. F. S.

Measurements in the Short Wave-Lengths of the Penetrating Radiation. E. REGENER. (*Physik. Zeit.*, March 15, 1929.) At the present time studies of the absorption of the penetrating radiation seem to offer the only clue to its nature. Steinke and also Millikan and Cameron agree in recognizing the composite character of the radiation though Steinke thinks that there are two constituents and the American investigators report three. The latter working with an apparatus sunk below the surface of lakes discovered that the ionization in it decreased as it was lowered beneath the surface until a depth of 50 m. was reached. No further decrease was caused by increasing the depth to 60 m. Regener set himself the

problem of finding whether there are harder rays in the penetrating radiation than those found by Millikan and Cameron. In the fall of 1928 he conducted his experiments in Lake Constance. His ionization chamber was a steel bomb holding 39 l. of carbon dioxide at a pressure of 30 atmospheres. A central electrode was connected to an electrometer which was initially charged to 600 volts. Every hour the fiber of the instrument was photographed in the position to which it had drifted owing to loss of voltage due to ionization. By zinc plating the inside of the bomb and by carefully purifying and drying the contained gas there was scarcely any trace left of ionization due to the material of the apparatus itself. Reproductions are printed of the hourly photographs. They are very regular. With the apparatus 32.4 m. below the surface the pictures of the fibers are about five times as far apart as at a depth of 230.8 m. This means that the loss of voltage in the first case was about five times as great in an hour as in the second. The losses are given as 4.33 and .83 volts respectively. In the following table the loss in volts/hour is given after deduction of the loss caused by the apparatus itself.

Depth in m.....	32.4	78.6	105.2	153.5	173.6	186.3	230.8
Volts/hour.....	3.55	.87	.53	.22	.15	.106	.051

At the surface of the water the hourly loss was about 40 volts. It is to be noted that the decrease of ionization continues to a depth of 230 m. From the absorption coefficient deduced from the above results the wave-length of the hardest, i.e., shortest wave-length component of the penetrating radiation is calculated to be from 4.6 to .6 times 10^{-13} cm. according to the formula used. This wave-length is believed to correspond roughly to that which would result from the transformation of a proton into radiation.

For their experiments Millikan and Cameron selected lakes fed by glacier water to avoid radioactive contamination. While Lake Constance receives much water from glaciers brought to it by the Rhine it is by no means free from suspicion of having in its basin radioactive material. Regener is preparing to repeat his experiments in such a way as to eliminate this possible influence. His results indicate the existence of harder penetrating rays than any previously found. G. F. S.

On the Imperfections of Crystals. F. ZWICKY. (*Proc. Nat. Acad. Sciences*, March, 1929.) There is a wide discrepancy between the theoretical breaking strength of crystals and that actually found by experiment. From theoretical considerations based on

the surface tension of the crystal it is calculated that the breaking strength of NaCl crystals should be of the order of 30,000 kg. per sq. cm. The experimental value, however, is less than one per cent. of this, viz., 50 kg./cm.^{2} A careful review of the theory failed to disclose any way of reconciling it with experiment. In addition many measurements of the breaking strength were made. "An NaCl crystal, for instance, whose surface is wetted will stand stresses as high as 16,000 kg./cm.^{2} before breaking, a value very near to the theoretically deduced strength. On application of great thermal gradients to a NaCl sphere stresses were produced in the center of the sphere as high as 7,000 kg./cm.^{2} without causing rupture. The experimental results then seem to prove that, proper conditions being observed, an NaCl crystal will in fact exhibit the strength required by the theory. There arose now the question as to the cause of the low breaking strength of the crystals in the dry state." In explanation Griffith suggested the existence of fine cracks on the surface. Upon application of a small average stress rupture would follow on account of the high stress developed at the edges of the cracks. Smekal "thinks that actual crystals are never of an ideal geometrical structure but are made up of a great many microscopic blocks leaving cracks and other imperfections between them. Smekal correlated this conception with a great many facts such as electric conductivity, electric strength, photoelectric absorption, etc. He succeeded in determining the size of the elementary blocks in a half empirical way and he found that they contain in the case of rocksalt and in many other cases about 10,000 atoms each. As Smekal's considerations enable us to understand a great number of facts it has to be concluded that the formation of cracks and blocks cannot be of a purely accidental nature. Otherwise, the surface cracks should occur in all kinds of different sizes on different samples. But then, it is impossible to understand why the technical breaking strength is a relatively well-defined quantity, as the different samples of a crystal would break on application of widely varied specific stresses." Zwicky then proceeds to calculate on theoretical grounds the depth of the largest crack and finds it to be about 50 Å. The number of atoms in an elementary block turns out to be about 10,000 in entire agreement with Smekal's result which was derived in a different manner.

It seems likely that under controlled conditions crystals can be grown without their breaking up into small blocks. Indeed certain organic crystals are known which are stable while they are in the saturated solution but which break up when their surface dries. The instabilities connected with cold hardening may have here their explanation. "It is also comprehensible now why an apparently

trivial conditioning of the surface like wetting rocksalt with water produces the enormous strengthening mentioned above. We know from the interionic theory of strong electrolytes, that the ions in the saturated solution will influence the ions in the solid surface in nearly the same way as the ions arranged in lattice planes below the surface. The crystal, therefore is much strenghened as far as rupture is concerned." G. F. S.

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